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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Reduced Support Needed for
Lunar Missions with Shortened
Launch Windows

TM- 68-2013-4

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ABSTRACT

An analysis has been made of the reduction in the required number of Manned Space Flight Network (MSFN) land stations and ships, Apollo/Range Instrumentation Aircraft (A/RIA), Atlantic launch abort recovery ships and aircraft, and Pacific earth orbit abort recovery ships and aircraft as the launch window for Apollo lunar missions is shortened. It has been shown that in several areas of support there are savings which are dependent on the reduction in the launch window. In addition, savings are suggested which are essentially independent of the launch window reduction. Although the suggested savings could be made on the first lunar mission, it is likely that the existing support forces will be used to the maximum extent on the early missions even though the support requirements may be exceeded.

Using current officially accepted ground rules for minimum tracking, communications and abort support, the effect of launch window reduction has been studied by moving the launch azimuth limits symmetrically toward 90°. A 26° launch azimuth sector was the maximum considered since the insertion tracking ship can cover no more than this sector. In reducing the window from the 3.5 hour value for the 26° sector, the following conclusions were obtained: (1) the MSFN stations at Antigua, Canary Island, and either Texas or Guaymas would not be required; (2) only 2 of the 3 tracking ships available would be required for launch windows up to at least 3.1 hours, 1 for insertion and 1 for translunar injection; (3) as few as 4 of the 8 A/RIA would be required for windows less than 1.5 hours in duration; (4) only 3 of the 4 launch abort recovery ships would be needed for windows shorter than 2.2 hours; and (5) only 1 ship and 1 aircraft of the present fleet of 3 ships and 3 aircraft from the Pacific earth orbit abort complement are needed to give recovery times less than the maximum specified in the launch abort recovery area for any launch window.

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BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W.

WASHINGTON, D. C. 20024

SUBJECT: Reduced Support Needed for Lunar
Missions with Shortened Launch
Windows - Case 310 and 900

DATE: September 23, 1968

FROM: P. A. Cavedo
T. B. Hoekstra

TM-68-2013-4

TECHNICAL MEMORANDUM

INTRODUCTION

A reduction in the duration of the launch window for Apollo lunar missions can be used to lower the number of ships, aircraft, and tracking stations necessary to support a mission. A previous memorandum (Reference 1) analyzes the effects on several support requirements resulting from a reduction in the duration of the launch window. Reference 1 emphasizes analysis of the case in which the launch window is reduced to essentially zero hours (launch-on-time). The analysis shows that significant savings can be realized in the number of support ships and aircraft if launch-on-time is used.

Clearly, if launch-on-time can bring a significant reduction in the size of the support force, there must be support force reductions for launch windows which are shorter than those currently planned (up to 4.5 hours) but greater than zero. The analysis in this memorandum indicates the break points in support required (ships, aircraft, and tracking stations) as the launch window is reduced continuously from its current duration to launch-on-time. The areas considered are MSFN stations including tracking ships, Apollo/Range Instrumentation Aircraft (A/RIA), Atlantic launch abort recovery ships and aircraft, and Pacific abort recovery ships and aircraft.

It is highly likely that the initial lunar landing mission will utilize all of the current ships, aircraft, and tracking stations to the fullest extent possible even though the minimum support requirements may be exceeded. However, on subsequent missions, as confidence grows, it is likely that support satisfying the minimum requirements, but not greatly exceeding them, will be acceptable. Hence, the following analysis is largely concerned with Apollo lunar missions (lunar orbital or lunar landing) beyond the first. Apollo test missions and Apollo Applications Program missions are not considered.

ASSUMPTIONS

It is assumed that the launch window is reduced by symmetrically moving the launch azimuth limits toward 90° . Symmetrical launch azimuth limits are preferred because the launch vehicle payload is maximum for a 90° launch azimuth and the payload drops almost equally (and parabolically) as the azimuth deviates in either direction from 90° . Figure 1 shows this variation. So, for a given window duration, launch vehicle payload is maximized if the launch azimuth limits are symmetrical about 90° . Figure 2 shows the launch window duration for various symmetrical azimuth sectors.

Translunar injection occurring on either the second or third earth parking orbit revolution is considered; in addition only Atlantic injections or only Pacific injections are considered during a given monthly launch opportunity.

Finally, the constraints listed in the Joint MSC/MSFC Reference Constraints document (Reference 2) have been used in this analysis except as noted in the text.

MANNED SPACE FLIGHT NETWORK (MSFN)

The MSFN, including land stations, tracking ships, and A/RIA is analyzed in terms of the numbers of land stations, ships, and aircraft required as a function of the duration of the launch window.

Requirements (Reference 2)

- . Launch Phase

Continuous tracking, command, telemetry, and voice coverage above 5° elevation for both the spacecraft and launch vehicle is required from liftoff through insertion plus 3 minutes.

- . Earth Parking Orbit

A minimum of two tracking, command, telemetry, and voice contacts of 4 minutes minimum duration above 5° * elevation is required prior to translunar injection (TLI). If injection does not occur in the 1st revolution, 2 such contacts are required per revolution.

*An exception is noted in the "Assumptions for Tracking Analysis" section which follows.

. Pre-TLI

At least one 4-minute contact above 5°* elevation with a ground station having command, telemetry, and voice capability is required during the one hour period beginning 90 minutes before and ending 30 minutes before TLI ignition. (TLI may occur from 80 to 270 minutes after insertion into earth parking orbit.)

. TLI

Aircraft for recording of CSM and S-IVB telemetry and recording and relaying of CSM voice are required from 1 minute prior to burn initiation until 1 minute after burn completion. Mission planning should not be constrained by this rule.

. Post-TLI

Continuous tracking, telemetry, and voice are required for a 10 minute period within the first 20 minutes after TLI cutoff.

. Lunar

Of the several lunar phase requirements, the requirement for continuous tracking, command, telemetry, and voice capability while the CSM and LM are in lunar parking orbit (and not eclipsed by the moon), necessitates continuous coverage during this phase of the mission.

Assumptions for Tracking Analysis

The assumptions and constraints used in making this study are as follows:

- . Acquisition of the spacecraft by a land station or ship is achieved when the vehicle elevation angle is 5 degrees above the local horizon.
- . Loss of tracking, communications and telemetry is assumed when the elevation angle decreases to 3 degrees above the local horizon. Although Reference 2

*An exception is noted in the "Assumptions for Tracking Analysis" section which follows.

states a need for 4-minute passes above a 5° elevation, signal loss generally occurs at a lower angle than does signal acquisition and 3° is a reasonable choice.

- . The antenna keyhole is taken into account for the ground stations. Two studies were made: 1) the keyhole is described as a 15 degree half-angle cone, and 2) the keyhole is described as a 10 degree half-angle cone. Reference 3 states that the keyholes will be approximately 14° *. Land stations equipped with a 30-foot diameter antenna (Grand Canary, Ascension Island, Carnarvon, Guam, Texas, Hawaii, Guaymas, Merritt Island, Grand Bahama Island, Bermuda, and Antigua) have keyholes centered along the 0-180 degree azimuths with the center of the cone at a zero degree elevation. The deep space stations having an 85-foot diameter antenna (Madrid, Canberra, and Goldstone) have keyholes centered along the 90-270 degree azimuths.
- . Coverage is considered adequate when the spacecraft is continuously visible to the station or ship for 4 minutes.
- . The altitude of the spacecraft in earth parking orbit is 100 nautical miles.
- . The antenna keyhole effect need not be considered for the tracking ships because of the ships' mobility. (The keyhole for tracking ships is about a 10° half-angle cone with an axis perpendicular to the earth's surface.)

Launch Phase

During the launch phase (liftoff to 3 minutes after insertion into parking orbit), 4 Unified S-Band (USB) stations and several positions of the Insertion ship were considered to determine the communications and tracking coverage.

Three of the USB stations (Merritt Island, Grand Bahama Island, and Bermuda) and the Insertion ship were found to provide adequate coverage for a launch window duration of 3.5 hours (a 26° azimuth sector). The location of the USB stations and the ships used in the final study are given in Table I. The difference

*In both studies the keyhole is described as a 6 degree half-angle cone for Bermuda. The 14° angle is an adjustable electrical pre-limit. The dead-limit occurs at 10° and is not adjustable without antenna modifications. The analysis of 10° and 15° keyholes brackets the expected keyhole range.

in the size of the keyholes (15° and 10°) does not affect the launch phase since Bermuda is the only station required in which the vehicle enters the keyhole and a 6° half-angle cone was always used for Bermuda.

The launch phase coverage provided by the USB stations and the Insertion ship at the position selected is shown in Figure 3. As can be seen, Antigua is not needed to meet the current tracking and communications requirements for a symmetrical 26° azimuth sector. It should be noted that there is an area of incomplete coverage between Bermuda and the position chosen for the Insertion ship for launch azimuths greater than 104° . If the requirements change to include launch azimuth sectors greater than about 28° (equivalent to about 3.7 hours of launch window), Antigua would be needed to supplement the ship coverage.

Earth Parking Orbit and Pre-TLI

During the earth parking orbit phase, 2 passes of at least 4 minutes duration each are required for tracking, command, telemetry, and voice contacts during each revolution. The pre-TLI phase requires only 1 pass between 90 and 30 minutes before ignition. TLI ignition occurs not later than 270 minutes after insertion into earth parking orbit. These separate requirements have been further clarified by MSC (Reference 4) to mean that if TLI occurs earlier than 30 minutes into the 2nd revolution, 2 passes would be required in the 1st revolution and none is required in the 2nd revolution. However, if TLI occurs later than 30 minutes into the 2nd revolution, then 2 passes are required in the 1st revolution and 1 pass is required in the 2nd revolution if TLI occurs more than 90 minutes after the last pass in the 1st orbit. If TLI occurs earlier than 30 minutes into the 3rd revolution, 2 passes are required in both the 1st and 2nd revolution and none in the 3rd revolution. When TLI occurs later than 30 minutes into the 3rd revolution, 2 passes are required in both the 1st and 2nd revolution and 1 contact is required in the 3rd revolution if TLI occurs more than 90 minutes after the last pass in the 2nd orbit. Nominally TLI will occur before the end of the 3rd earth parking orbit. However, in the event TLI fails to occur, at least 1 pass would be needed during the 4th orbit.

Tracking and communications during the earth parking orbit and pre-TLI phases of the mission were studied using all 14 USB stations and variable placement of the Insertion ship and the TLI ship. Bar charts of the coverage by each of the USB stations and the final choices for positions of the Insertion ship and TLI ship are given in Figures 4a and 4b. The solid lines represent a minimum of 4 minutes of continuous tracking, command, telemetry, and voice contact for each station and ship. The

dotted lines represent a minimum of 3 minutes coverage. Since the exact sizes of the antenna keyholes has been in question, this analysis has studied both a 10° and 15° antenna keyhole. Figure 4a represents the coverage provided for a 10° antenna keyhole, whereas, Figure 4b describes the coverage for an antenna keyhole of 15° . In both figures the antenna keyhole for Bermuda is 6° .

The number of USB stations and ships required to provide adequate coverage (2 contacts of 4 minutes each) is a function of the duration of the launch window and the size of the antenna keyhole. The requirement of 4 minutes continuous coverage eliminates any station which provides a total coverage of 4 minutes if the vehicle enters the keyhole during this 4 minute period. For most stations (Goldstone is an exception) when the trajectory is such that the vehicle passes through the keyhole at all, the resulting coverage provided will not meet this requirement. As a result, the coverage provided by the USB stations is greatly improved when assuming the antenna keyhole is 10° .

Assuming an antenna keyhole of 10° , the satisfaction of the parking orbit and pre-TLI requirements with launch-on-time (using a launch azimuth of 90°) requires only the TLI ship and Texas. These two stations satisfy the requirements for a launch window duration of up to 2 hours. A launch window duration of 2 hours would necessitate the addition of Carnarvon to satisfy the requirements. Extending the launch window duration beyond 2.9 hours requires the substitution of Guaymas for Texas to provide adequate coverage. Guaymas, Carnarvon and the TLI ship will satisfy all the requirements during the earth parking orbit and pre-TLI phases for a launch window duration of up to 3.5 hours. The chart in Figure 5a describes pictorially these break points for an antenna keyhole of 10° . Figure 7a also summarizes these results in the column labeled EPO and PRE-TLI.

If the antenna keyhole is assumed to be 15° , the number of USB stations and ships needed to satisfy the requirements is different in terms of the launch window duration. For launch-on-time (launch azimuth of 90°), the TLI ship and Texas satisfy the earth parking orbit and pre-TLI requirements. Texas and the TLI ship together provide adequate coverage for a launch window duration of up to 1.5 hours. When the launch window duration is extended beyond 1.5 hours, it is necessary for Guaymas to replace Texas to satisfy the requirements. The addition of Carnarvon is necessary when the launch window duration is 2 hours. Carnarvon, Guaymas and the TLI ship will provide adequate coverage for a launch window duration of up to 3.1 hours assuming the 15° antenna keyhole. An additional ship located in the Pacific Ocean would be required to supplement Carnarvon for low launch azimuths if the launch window duration were to be extended beyond 3.1 hours.

No existing land station can eliminate the need for this ship if the tracking requirements are to be strictly met*. The chart in Figure 5b shows pictorially these break points of stations required as a function of the duration of the launch window for a 15° antenna keyhole. Figure 7b summarizes the results for an antenna keyhole of 15° in the column labeled EPO and PRE-TLI.

Careful examination of Figures 4a and 4b shows that relaxing the requirement to 3 minutes of continuous coverage rather than 4 minutes does not alter the total number of USB stations and ships required for a launch window duration of 3.5 hours. However, the break points in terms of adding or substituting stations as the launch window duration varies would be slightly different. Assuming a 10° antenna keyhole, Carnarvon would not be required to supplement the TLI ship and Texas until the duration of the launch window was extended beyond 2.75 hours. The substitution of Guaymas for Texas would not be required until the duration of the launch window was greater than 2.9 hours.

Assuming a 15° antenna keyhole and permitting 3 minutes of tracking instead of 4 minutes as adequate coverage, Carnarvon would not be required until the launch window duration was extended beyond 2.75 hours. The replacement of Texas with Guaymas would still be necessary at a 1.5 hour launch window to meet the requirements.

Post-TLI Coverage

There must be continuous coverage for a 10 minute period during the first 20 minutes after TLI. The radii of the coverage circles for the MSFN land stations and ships expand rapidly as time passes after TLI. For example with a 5° masking angle, the coverage circle radius is about 750 n.m. for a spacecraft altitude of 163 n.m. (TLI cutoff) and 2200 n.m. in radius for a 1220 n.m. spacecraft altitude (TLI + 10 minutes).

Ten minutes after TLI cutoff 5 land stations and the Insertion ship can cover all possible sub-spacecraft points with the exception of a region in the Indian Ocean. By placing a tracking ship (called the TLI ship) in the Indian Ocean this region is covered. The land stations used are Hawaii, Texas, Ascension, Carnarvon, and Guam.

Figure 6 shows the coverage boundaries (5° masking angles), for these stations and ships 10 minutes after TLI cutoff. The

*If the southern keyhole at Carnarvon were less than 13°, the launch window could be as long as 3.5 hours without the Pacific ship.

station locations used are indicated by a square. The shaded areas are possible spacecraft locations at the 10 minute point for the full 36° azimuth sector from 72° to 108° . Since all possible sub-spacecraft points are covered 10 minutes after TLI and since the coverage circles are expanding rapidly, contact will be maintained continuously at least until 20 minutes after TLI cutoff. Therefore, the post-TLI tracking requirements can be satisfied with the 5 land stations, the Insertion ship, and the TLI ship.

The columns labeled POST-TLI in Figures 7a and 7b list these stations and ships. It is seen that of all the communications and tracking requirements, the post-TLI phase requires the largest number of ships and land stations. Significantly, a reduction of the launch window to very small duration does not reduce the need for these stations and ships. Therefore, the support required in terms of post-TLI coverage is independent of the launch window reduction.

Lunar Phase Coverage

Three of the MSFN stations (Goldstone, Madrid, and Canberra) have 85 foot diameter antennas which are used primarily to satisfy the deep space communications and tracking requirements. These stations must be included and their inclusion is independent of the launch window duration. In Figures 7a and 7b these stations, are listed in the column labeled LUNAR. As shown in Figures 7a and 7b, these stations are not actually required for any other communications and tracking function during the entire mission. The use of 3-way Doppler Tracking improves the accuracy of deep space maneuvers, however, the elimination of Antigua and Texas or Guaymas will have virtually no effect on this capability. Eliminating Canary Island may slightly decrease the 3-way Doppler capability (particularly if data from an Apollo Lunar Surface Experiment Package is to be received simultaneously) but since the distance from Madrid to Canary Island is short, the contribution of Canary Island in terms of accuracy is not great.

Apollo/Range Instrumentation Aircraft (A/RIA)

The A/RIA are used to satisfy the requirement for voice relay and telemetry recording from 1 minute before TLI ignition until 1 minute after TLI cutoff. On a given day the TLI burn occurs at a point which is nearly stationary relative to an earth-moon fixed coordinate system. As time passes during the launch window, the TLI ignition point moves west on the earth's surface at a speed between about 750 and 900 knots (depending on latitude) due to the rotation of the earth. Thus, reducing the launch window cuts down the size of the geographic area which must be covered by the A/RIA.

The A/RIA have a cruise speed of about 400 knots, and so they cannot match the motion of the TLI burn ground track. However, this does not mean that they can cover only a small portion of the launch window. Once the launch vehicle lifts off, the launch azimuth is determined and the A/RIA have at least 90 minutes to move into position adjacent to the expected TLI burn ground track (since 1st revolution injections are not permitted). Taking advantage of this 90 minute period after lift-off before TLI ignition, the A/RIA can "lead" the moving ground track. This technique allows a given A/RIA to cover a minimum window about 2.5 hours in duration provided a sufficient number of staging and recovery bases is available for the aircraft. However, there are geographic areas where the staging and recovery bases are sparse enough that an aircraft cannot follow the east-west motion of the ground track throughout long launch windows.

Specifically, the Indian Ocean area appears to be most critical in terms of the number of A/RIA required. Coverage in this region was then presumed to be the determining factor in A/RIA requirements and was closely examined to determine the break points in the number of A/RIA required as a function of the launch window duration. In doing this analysis the following assumptions were used:

- (1) The maximum slant range for the A/RIA communications system is about 750 n.m. corresponding to a masking angle between 2° and 5° depending on space vehicle altitude. This means that 2 A/RIA can cover a given data interval. References 5 and 6 indicate that A/RIA S-Band will give good data down to a $2-5^\circ$ elevation, but that VHF reception will be degraded by multipath distortion. VHF reception is good above a 15° elevation giving a maximum slant range between 300 and 450 n.m. Three to 4 A/RIA would be needed to cover a given data interval to give good VHF reception. So it is assumed that continuous coverage will be provided only by S-band. In this analysis, an A/RIA will be eliminated only if the reduced fleet can provide coverage equal to that currently planned.
- (2) The A/RIA covering a given pass of the spacecraft are either all on the right or all on the left of the ground track. (The spacecraft antennas are manually switched for coverage on one side or the other by the astronauts but are not normally switched during a coverage pass.)

- (3) The cruise speed of an A/RIA is 400 knots. (This cruise speed accounts for the maximum expected headwinds.)

In the Indian Ocean region the following airfields are used as possible staging and recovery bases. The numbers in parentheses indicate the maximum flight time capability (hours and minutes) an A/RIA has when taking off from the base: Plaisance, Mauritius (7:20); Cocos Islands (7:55), Perth, Australia (9:05); and Darwin, Australia (9:50) (Reference 7). In the Indian Ocean, the most difficult cases to satisfy occur when the moon is at its maximum northern declination causing TLI ignition to occur near the 28°S latitude.

In this region it was found that 3 A/RIA can cover launch windows between zero and about 1.5 hours in duration. For launch windows between about 1.5 and 3 hours the requirement for A/RIA increases to 4. When the window duration reaches about 3 hours, 5 A/RIA are needed. Figure 8 shows the number of operational A/RIA needed as a function of the launch window duration. In addition to the 3, 4, or 5 A/RIA needed for actual support, 1 or 2 additional aircraft would likely be needed as spares. If the current ratio of 1 spare per 3 operational A/RIA is not degraded, the total number of A/RIA required, including spares, would be

0 - 1.5 hour window:	4 A/RIA
1.5 - 3.0 hour window:	6 A/RIA
greater than 3.0 hour window:	7 A/RIA

Thus, of the current fleet of 8 A/RIA, the required number for TLI coverage can be cut to as few as 4 by reducing the launch window if the assumptions used in this analysis prove to be reasonable.

LAUNCH ABORT RECOVERY FLEET

Current recovery planning (Reference 8) utilizes 4 ships and 3 aircraft to provide abort recovery in the Atlantic Ocean (these numbers do not include the ships and aircraft located in the pad abort area just off the Florida coast).

The philosophy taken in this analysis is to reduce the number of ships and/or aircraft as the launch window is reduced while not exceeding the currently anticipated maximum recovery

time for the present situation. Since plans for the deployment of the recovery ships and aircraft for lunar missions have not been completed, certain assumptions must be made concerning deployment strategy.

Launch Abort Recovery Ships

It is assumed that 4 ships are placed along the ground track of the azimuth at the center of the azimuth sector being considered (in this case 90° since azimuth limits symmetrical with respect to 90° are being considered). The ships are located along the ground track (up-range - downrange) so that the maximum recovery times are the same for each of the ships.

Figure 9a shows the general locations of the ships for the presently planned 26° azimuth sector. Placing the ships for equal maximum recovery times gives a maximum possible distance to be traveled by each of the 4 ships of about 600 n.m. If a 20 knot cruising speed is assumed for the recovery ships, the maximum time from the abort until the ship arrives in the vicinity of the spacecraft (arrival time) would be 30 hours.

As the launch window is reduced, the launch azimuth sector is decreased and therefore the maximum distance the ships would have to move decreases. Eventually a point is reached where 3, instead of 4, ships have a maximum distance to travel of 600 n.m. As shown in Figure 9b, this occurs when the launch azimuth sector is about 16° corresponding to a launch window about 2.2 hours in duration (when the azimuth sector is centered about 90°). If the azimuth sector is reduced to zero (launch-on-time), the maximum distance for recovery with only 2 ships would be 800 n.m. Thus, reducing the window can reduce the number of launch abort recovery ships from 4 to 3 but cannot reduce the requirement to 2 if equivalent recovery times are desired.

It is important to note that the 30 hour maximum arrival time indicated for the current 26° azimuth sector is somewhat optimistic. Considerable recovery planning (Reference 8) has been done with the recovery ships located at or near the ground track for the azimuth which opens the launch window. This is done to try to give the high probability cases the best coverage. Covering the high probability cases better means that the low probability cases (azimuths near the end of the window) will suffer in terms of recovery time so that the maximum arrival times would be significantly greater than 30 hours. In addition, the assumed 20 knot cruise speed may be optimistic. The cruise speed is dependent upon the type of recovery ship provided by the Department of Defense.

Launch Abort Aircraft

As discussed in Reference 1, there is no saving in launch abort aircraft even for launch-on-time since the 3 aircraft can essentially follow the motion of their assigned point along the ground track as the azimuth changes. The number of launch abort aircraft is a function of their ability to fly to any point uprange or downrange along the ground track and this does not change with launch window duration.

To summarize, a launch abort recovery ship can be saved if the launch window is less than 2.2 hours in duration but in no case can a launch abort aircraft be saved if equivalent coverage is to be maintained.

EARTH ORBIT ABORT RECOVERY FLEET

Provision is made for the recovery of the spacecraft at the end of the 1st, 2nd, 3rd, or 4th* earth parking orbit if an abort is necessary during any of these orbits. If an abort is necessary during the 1st orbit, the plan is to have a launch abort recovery ship recover the spacecraft in the Atlantic (really at the beginning of the second orbit). The maximum recovery time for this 1st orbit abort case can be quite high both with the nominal window and with the reduced window. Arrival times up to about 45 hours (with a 20 knot ship speed) occur for the high azimuth launches (late launches) within the current 26° sector. If the launch azimuth sector is reduced to 16° and 3 Atlantic ships are utilized, the maximum arrival time would be reduced to about 40 hours. So, 1st orbit abort recovery is not fast, but it is improved by reducing the launch window.

Recoveries for aborts necessitated on the 2nd, 3rd, or 4th orbits are planned for the Pacific Ocean. For each of these orbits there is a point in the Pacific Ocean over which the ground tracks for all azimuths pass. Figure 10 shows the locations of these 3 points in the Pacific (these points will be referred to as nodes).

The current plan is to place a ship and an aircraft at each of the 3 Pacific nodes for rapid recovery. In Reference 1 it is noted that a ship and an aircraft can be saved with no

*A 4th orbit abort could be needed if translunar injection fails near the end of the 3rd orbit.

sacrifice in recovery time if launch-on-time is used. By placing a ship and an aircraft at the intersection point of either the 2nd and 3rd or 3rd and 4th orbits, any 2 consecutive orbits can be covered. The remaining (2nd or 4th) orbit is covered with an additional ship and aircraft. As the launch window is expanded from launch-on-time the intersection point expands into an area. The lower part of Figure 10 shows this area for the full 36° azimuth sector. Since aborts to the Atlantic can have rather large recovery times, it is reasonable to consider this 2 orbit coverage scheme for finite launch windows to determine what maximum recovery time results in the case of Pacific aborts.

By placing a ship and an aircraft near the center of the area between the nodes, recoveries are possible on either of the 2 revolutions. The distance D shown in the lower part of Figure 10 for a simple north-south ship motion can actually be improved upon by moving the ship (which will be called the two-orbit recovery ship) in a slightly northwest-southeast direction for azimuths less than 90° and in a northeast-southwest direction for azimuths greater than 90° . An additional slight reduction in recovery times can be realized if the ship is biased slightly toward the ground track for the earlier of the 2 revolutions. The ship has 90 minutes to steam toward the next revolution ground track.

The lower solid curve in Figure 11 shows the maximum arrival time versus launch window duration when a single ship provides recoveries for 2 consecutive orbits (either 2nd or 3rd or 3rd and 4th). A 20 knot cruise speed is assumed and landing point dispersions have not been accounted for in this analysis. The lower dashed curve in Figure 11 shows the effect of biasing the ship location to take advantage of the 90 minute period between the two orbit passes. Even with a 3.5 hour window (26° azimuth sector) the maximum arrival time is only about 6.5 hours.

The two-orbit ship should be located at a longitude of 137.0°W if the 2nd and 3rd revolution areas are combined. Its prelaunch latitude should be 28.0°N if no bias is put in toward the 2nd orbit. The single orbit recovery ship in this case would cover the 4th orbit and it would be located at a longitude of 170.7°W and at a latitude of 28.4°N .*

*The Pacific node for the 4th orbit is located about 400 n.m. east of Midway Island so that the ship could remain in port until the actual abort situation arose. In this case it could arrive in the vicinity of the splashdown point within about 20 hours. Actually, the 4th orbit ground tracks all pass within about 180 n.m. of Midway. Therefore arrival would be available within about 9 hours if the spacecraft reentry were targeted along the ground track for near-Midway splashdown rather than splashdown at the node.

If the 3rd and 4th orbit recovery areas are combined, the two-orbit recovery ship should be located at a longitude of 159.5°W and a latitude of 28.0°N . The single orbit recovery ship would then be located at 125.7°W , 28.4°N .*

An additional ship and an additional aircraft can be saved if the recovery bases for the 2nd and 3rd and 4th orbits are combined. In this case a ship (called the three-orbit recovery ship) and an aircraft would be placed near the 3rd revolution node and recoveries on the 2nd or 4th revolutions would be made basically to the north or south of this point.

When only 2 orbits are covered by a ship and an aircraft use of launch-on-time allows the ship and aircraft to be placed at the intersection of the two ground tracks. When 3 revolutions are covered by a ship and an aircraft, even for launch-on-time, there is not a common intersection for all 3 orbits so the recovery time does not go to zero. The 2 upper curves in Figure 11 show the variation in the maximum arrival time with window duration when one ship covers aborts from the 2nd, 3rd, and 4th orbits in the Pacific. The solid curve shows the maximum arrival times when the ship is not biased toward the earlier revolutions and the dashed curve shows the improvement if it is. Figure 11 shows that the arrival time would be about 13 hours for an azimuth sector of 26° . This is well below the maximum arrival time for launch aborts.

The three-orbit recovery ship would be placed at a longitude of 148.2°W . The latitude depends slightly upon the launch window duration. For a launch window greater than about 2 hours in duration, the ship should be located at 26.6°N . As the launch window is decreased below 2 hours the desired latitude moves toward 27.5°N which is the optimum latitude for launch-on-time. Keeping the three-orbit recovery ship in port at Pearl Harbor would result in maximum arrival times up to about 40 hours.

Thus, 2 Pacific abort recovery ships and 2 Pacific abort recovery aircraft can be saved without causing the maximum recovery times to go beyond the values for the launch abort recovery area. If only 1 ship and 1 aircraft are eliminated, either 1 or both of the remaining 2 ships can be left in port until they are actually needed for abort recovery (without exceeding the maximum recovery times in the Atlantic).

*If the two-orbit recovery ship remains in port at Pearl Harbor until actually required for recovery, the maximum arrival time would be about 27 hours for a 3.5 hour window. A ship in port at San Diego would have a maximum arrival time of about 24 hours if the 2nd orbit abort splashdown were targeted for minimum recovery distance.

CONCLUSIONS

This analysis has shown that the savings in several areas of support for Apollo lunar missions are related to the reduction in the launch window. Up to 4 A/RIA can be saved (and coverage equal to that of the present fleet can still be provided) if the launch window is reduced to 1.5 hours or less. In addition a launch abort recovery ship can be saved if the window is shorter than 2.2 hours.

The number of MSFN stations required is almost independent of the launch window duration. For windows up to 3.5 hours in duration, Canary Island, Antigua, and either Guaymas or Texas can be eliminated. (The choice between Guaymas and Texas depends on the launch window duration and on the size of the station keyholes.) A Pacific Ocean ship is needed for launch windows greater than 3.1 hours if the keyholes are 15°. No existing land station can eliminate the need for the Pacific ship under these conditions; however, if the southern keyhole at Carnarvon were reduced to 13°, the Pacific ship would not be needed for windows up to 3.5 hours long. So, for windows up to at least 3.1 hours in duration only 2 tracking ships are needed: one for earth parking orbit insertion coverage and the other for TLI coverage (and earth parking orbit coverage).

The Pacific abort recovery fleet can be reduced from 3 ships and 3 aircraft to 1 ship and 1 aircraft without causing the maximum recovery time to exceed the 40 hour maximum specified in the launch abort recovery area.

Thus, MSFN land station and tracking ship savings as well as Pacific abort ship and aircraft savings are basically independent of the launch window reduction while A/RIA savings and the launch abort ship saving are dependent on the reduction.

2013-PAC
-TBH-srb

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T. B. Hoekstra
T. B. Hoekstra

Attachments:
References
Table 1
Figures 1 - 11

BELLCOMM, INC.

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3. Memorandum from FS/Chief, Flight Support Division to FA/Technical Assistant for Apollo titled MSFN Capabilities for "D" and Subsequent Missions, June 18, 1968.
4. Telephone Communication with W. E. Platt, Jr. Code FC, MSC August 30, 1968.
5. "MSFN Postmission Report on the AS-204 LM Mission", Goddard Space Flight Center Report, May 1968, Section 10.
6. "MSFN Postmission Report on the AS-502 Mission", Goddard Space Flight Center Report, June 1968, Section 7.
7. Personal Communication with Maj. D. J. DiFabio/AOCC, Patrick Air Force Base, Florida, July 23, 1968.
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TABLE I
UNIFIED S-BAND STATIONS AND SHIPS

STATION NAME	CALL LETTERS	LATITUDE (DEGREES)	LONGITUDE (DEGREES)	GEOCENTRIC RADIUS (METERS)
MERRITT ISLAND	MLA	28.51 N	80.69 W	6373336.
GRAND BAHAMA ISLAND	GBI	26.63 N	78.24 W	6373916.
BERMUDA	BDA	32.35 N	64.66 W	6372101.
INSERTION SHIP	INS SHIP	25.00 N	50.00 W	6376360.
ANTIGUA	ANT	17.02 N	61.75 W	6376376.
CANARY ISLAND	CYI	27.74 N	15.60 W	6373604.
MADRID	MAD	40.45 N	4.17 W	6370033.
ASCENSION	ASC	7.95 S	14.33 W	6378321.
INJECTION SHIP	TLI SHIP	25.00 S	48.00 E	6376360.
CARNARVON	CRO	24.91 S	113.72 E	6374458.
CANBERRA	CNB	35.58 S	148.98 E	6372114.
GUAM	GWM	13.31 N	144.73 E	6377169.
HAWAII	HAW	22.12 N	159.66 W	6376305.
GOLDSTONE	GDS	35.34 N	116.87 W	6372064.
GUAYMAS	GYM	27.96 N	110.72 W	6373515.
TEXAS	TEX	27.65 N	97.38 W	6373600.

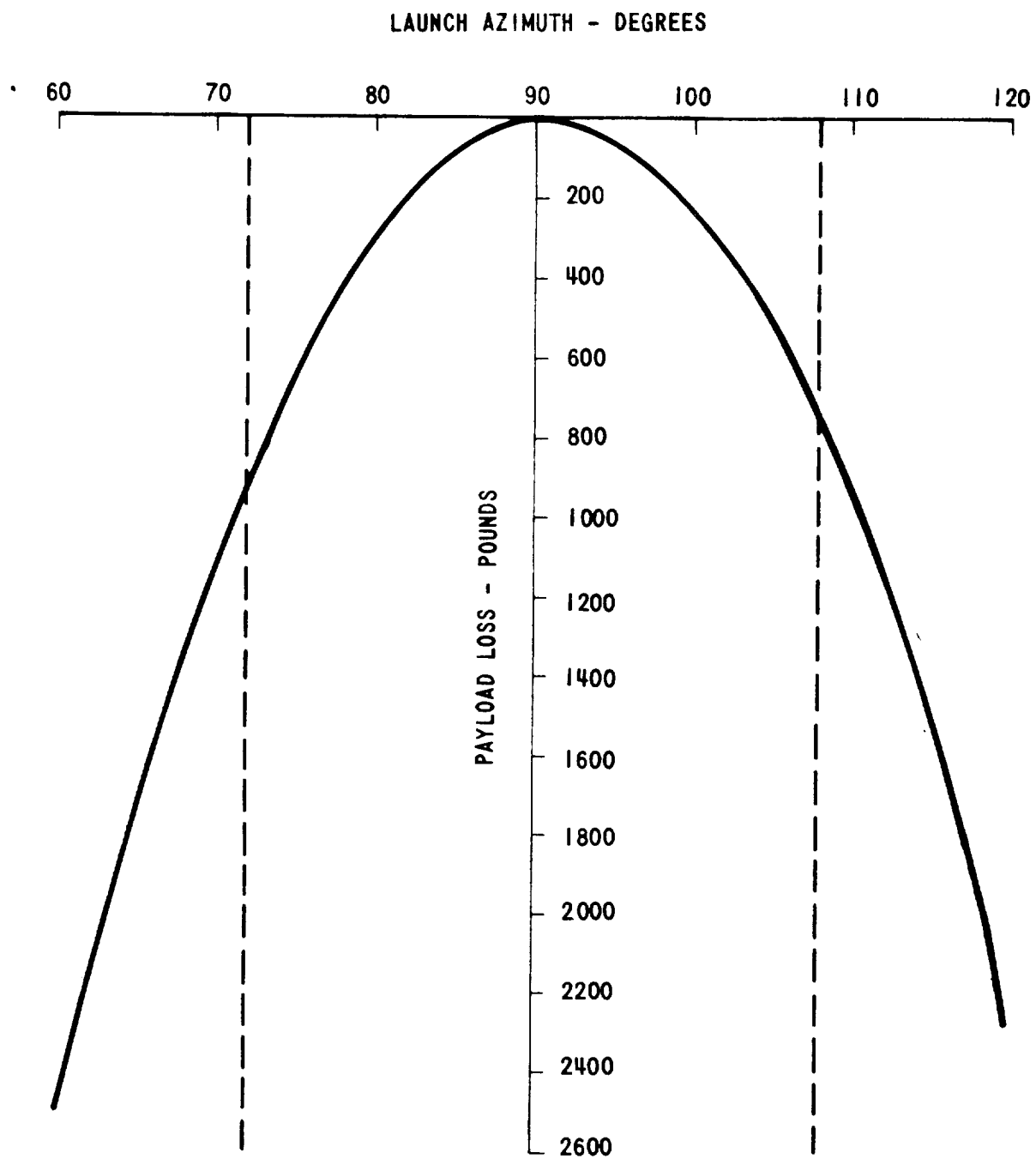


FIGURE 1 - LAUNCH VEHICLE PAYLOAD LOSS FOR VARIOUS LAUNCH AZIMUTHS

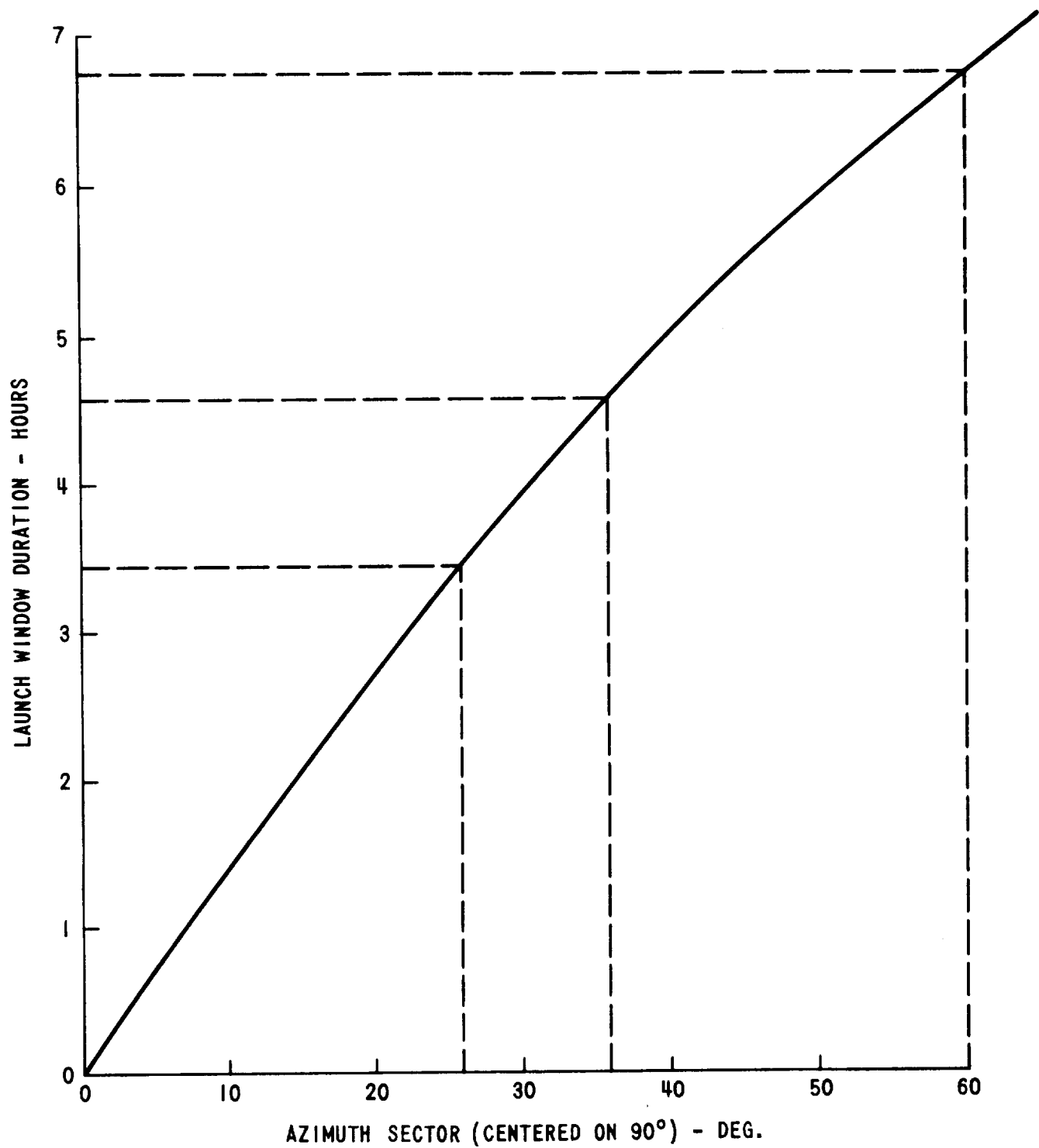


FIGURE 2 - LAUNCH WINDOW DURATION FOR VARIOUS LAUNCH AZIMUTH SECTORS
(AZIMUTH SPREAD CENTERED ON 90°)

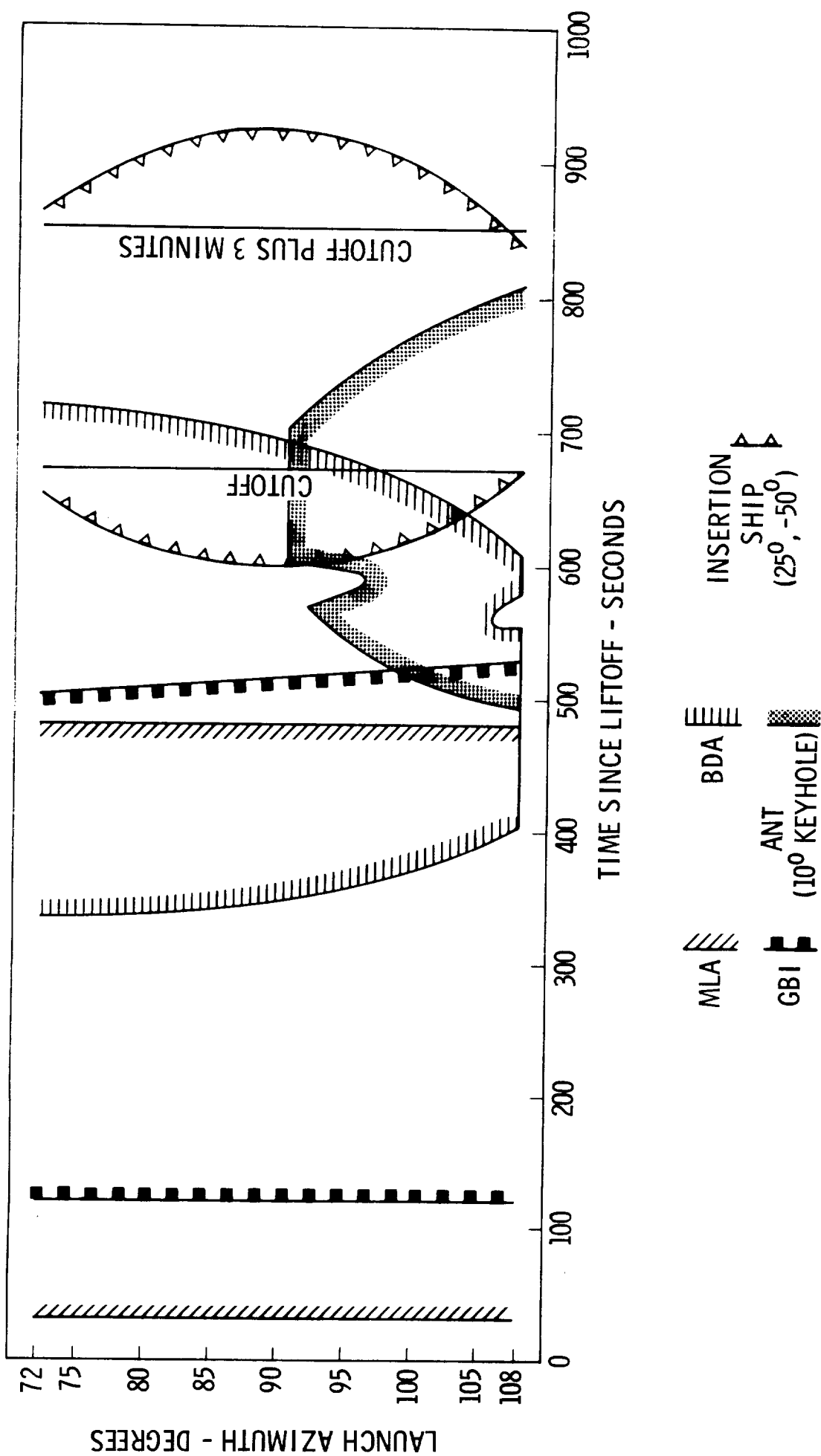


FIGURE 3 - LAUNCH PHASE S-BAND COVERAGE

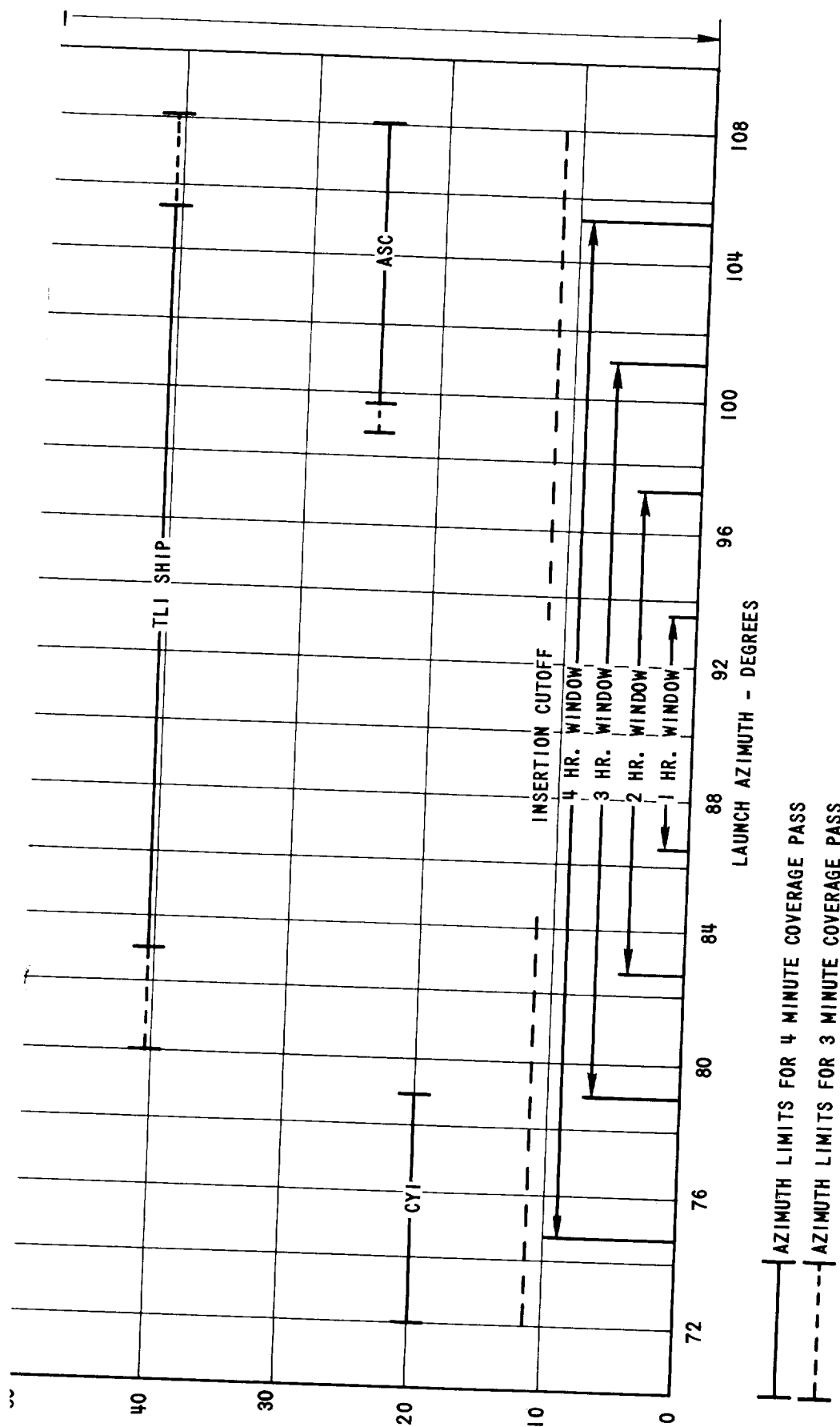
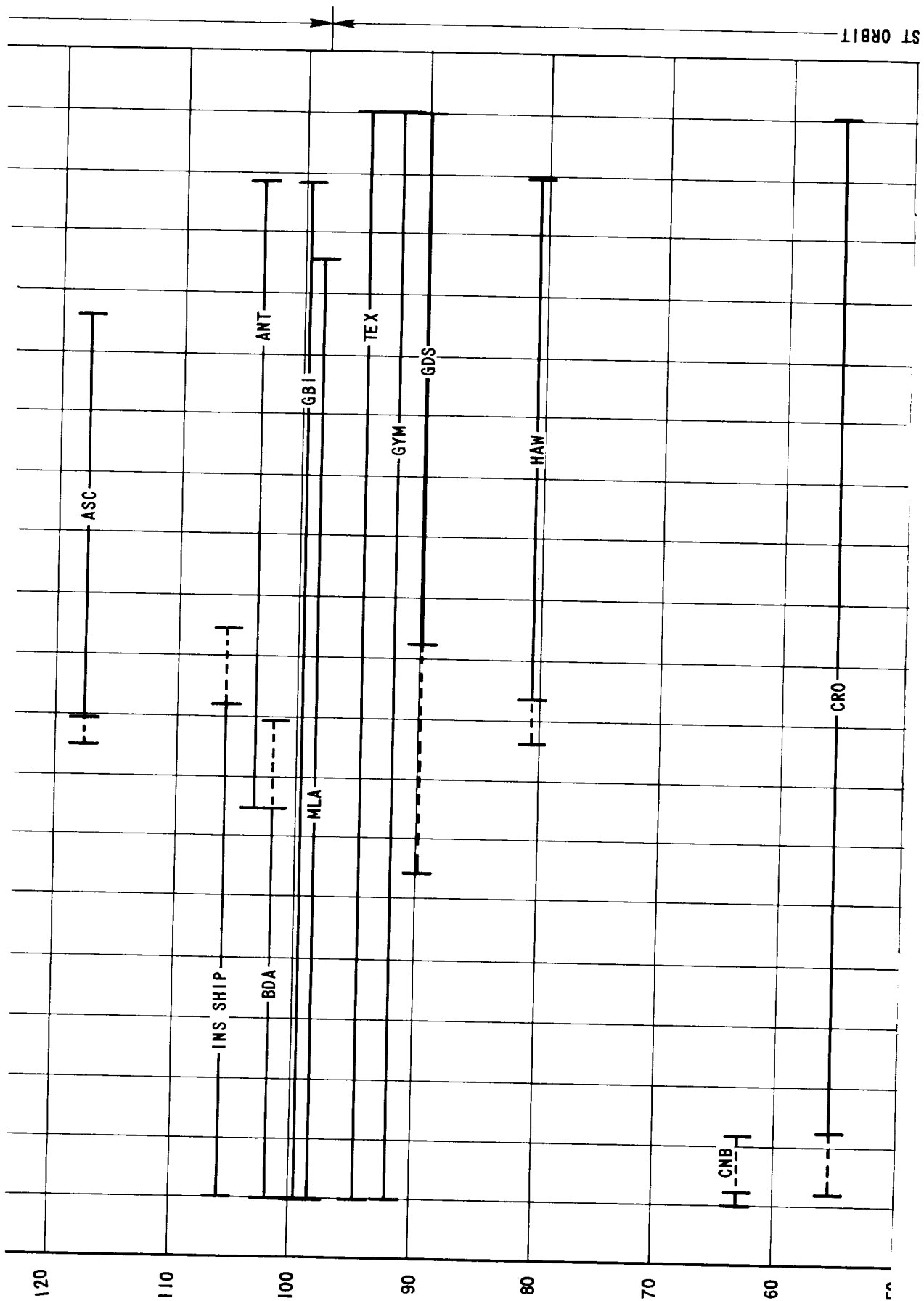
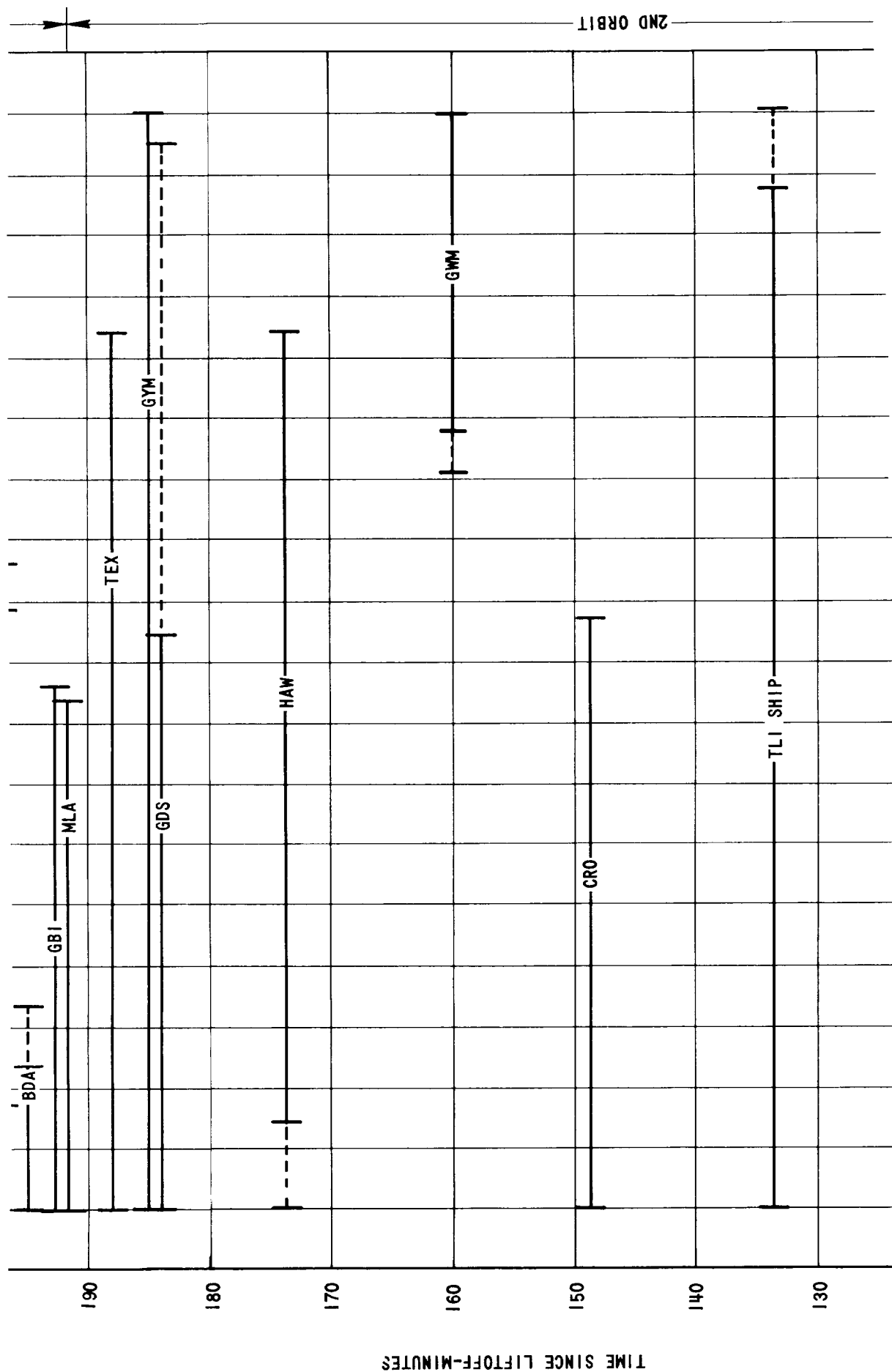
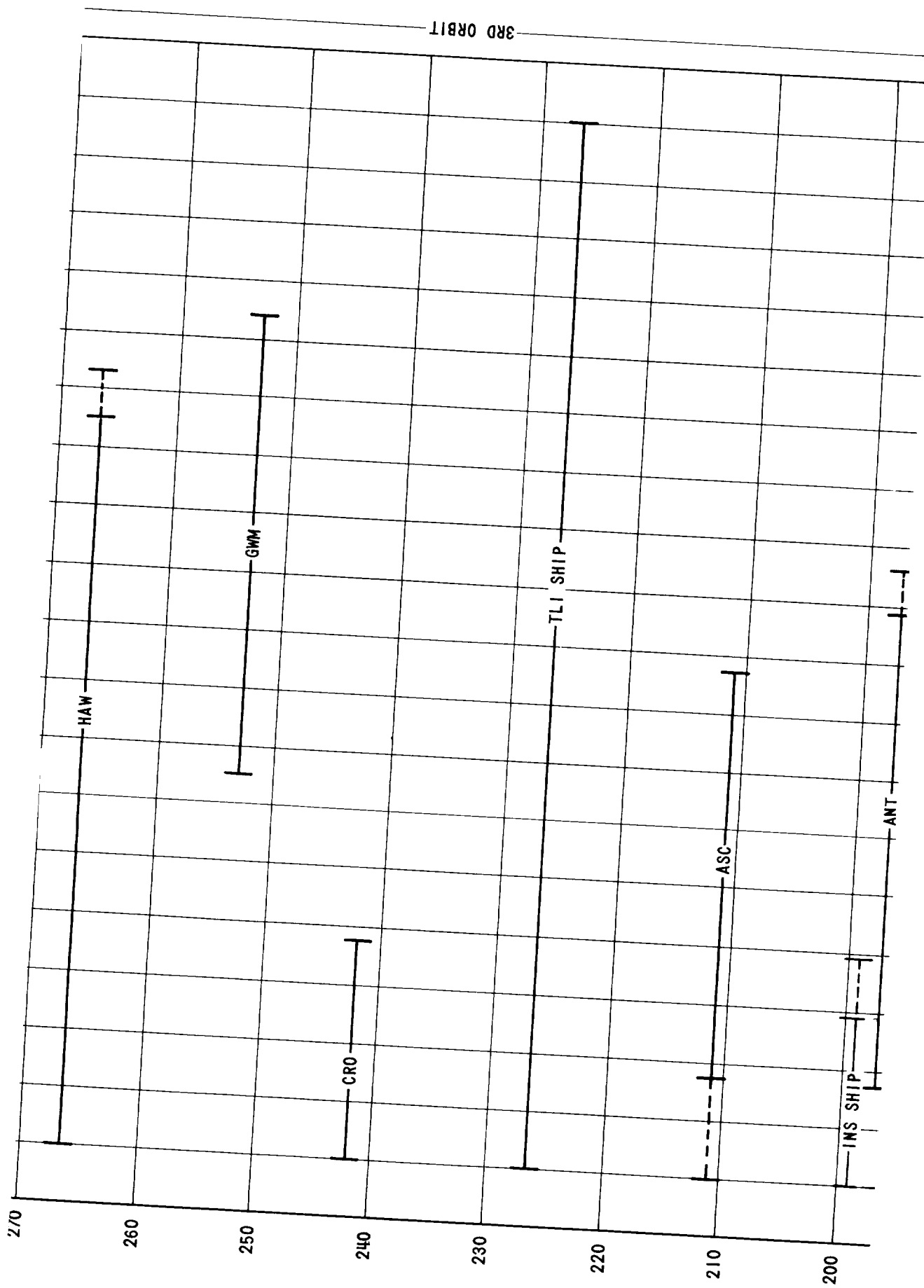
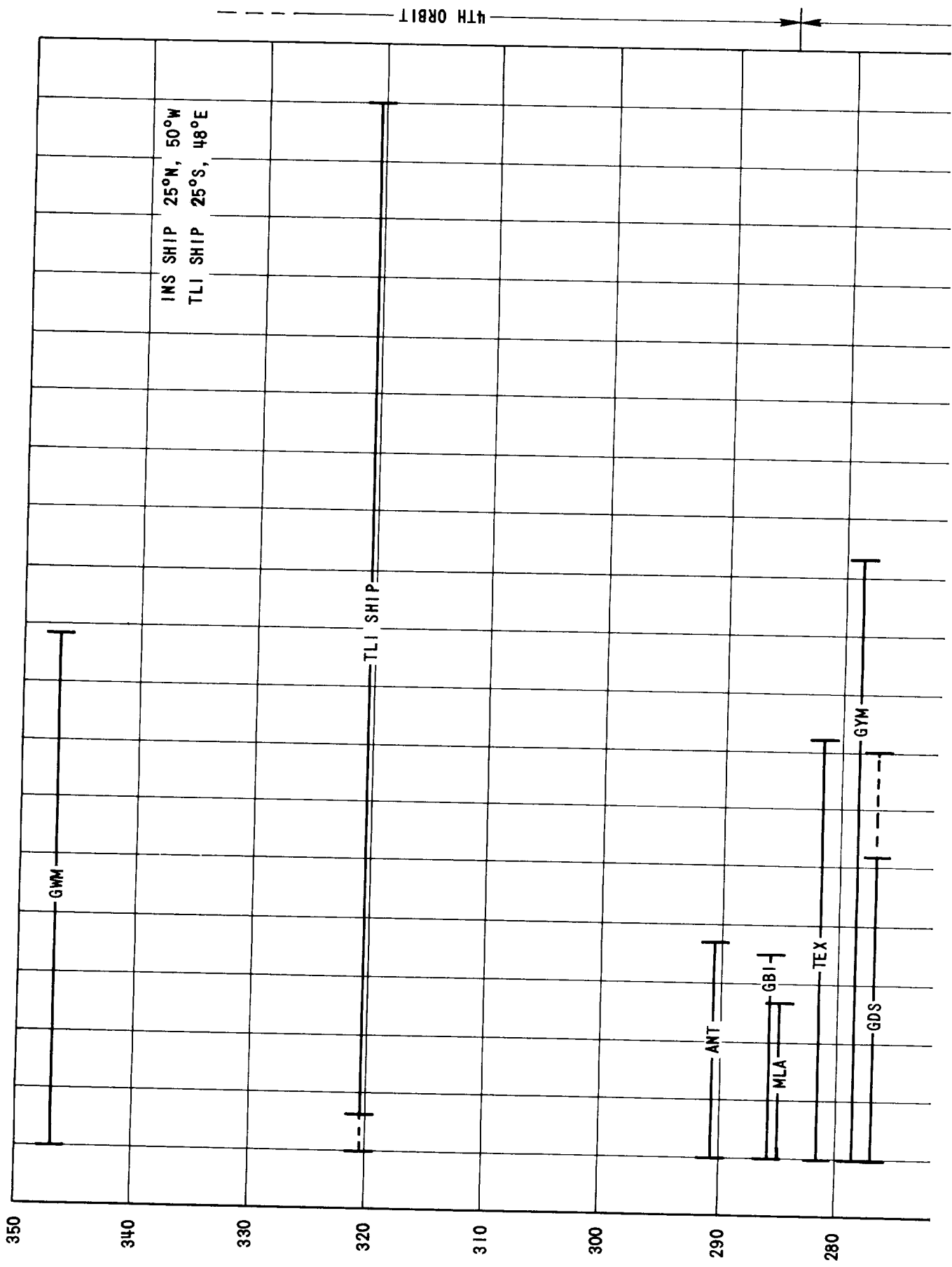


FIGURE 4a - S-BAND TRACKING COVERAGE DURING EARTH PARKING ORBIT
WITH 10° KEYHOLES (EXCEPT 6° KEYHOLES AT BERMUDA)









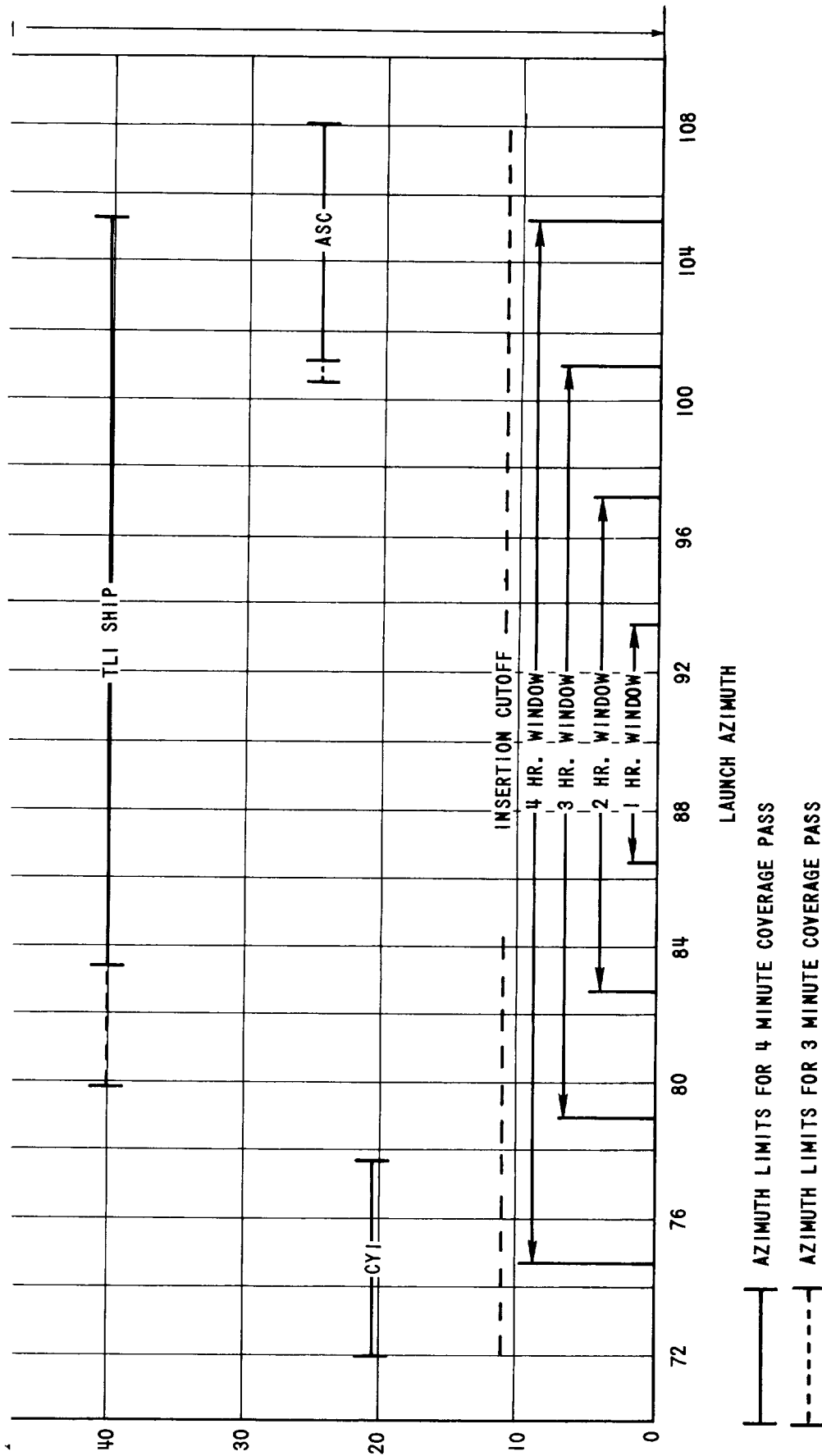
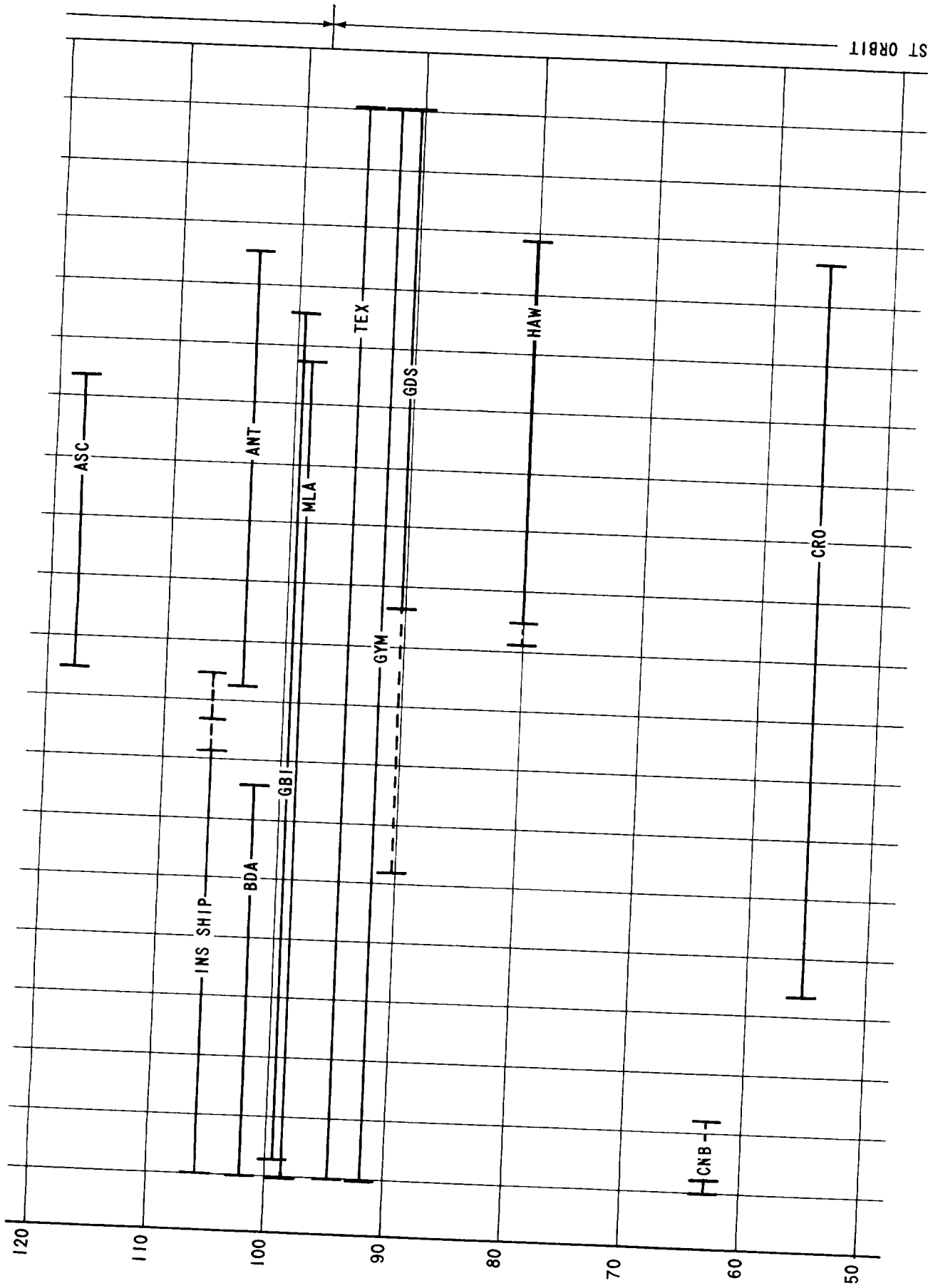
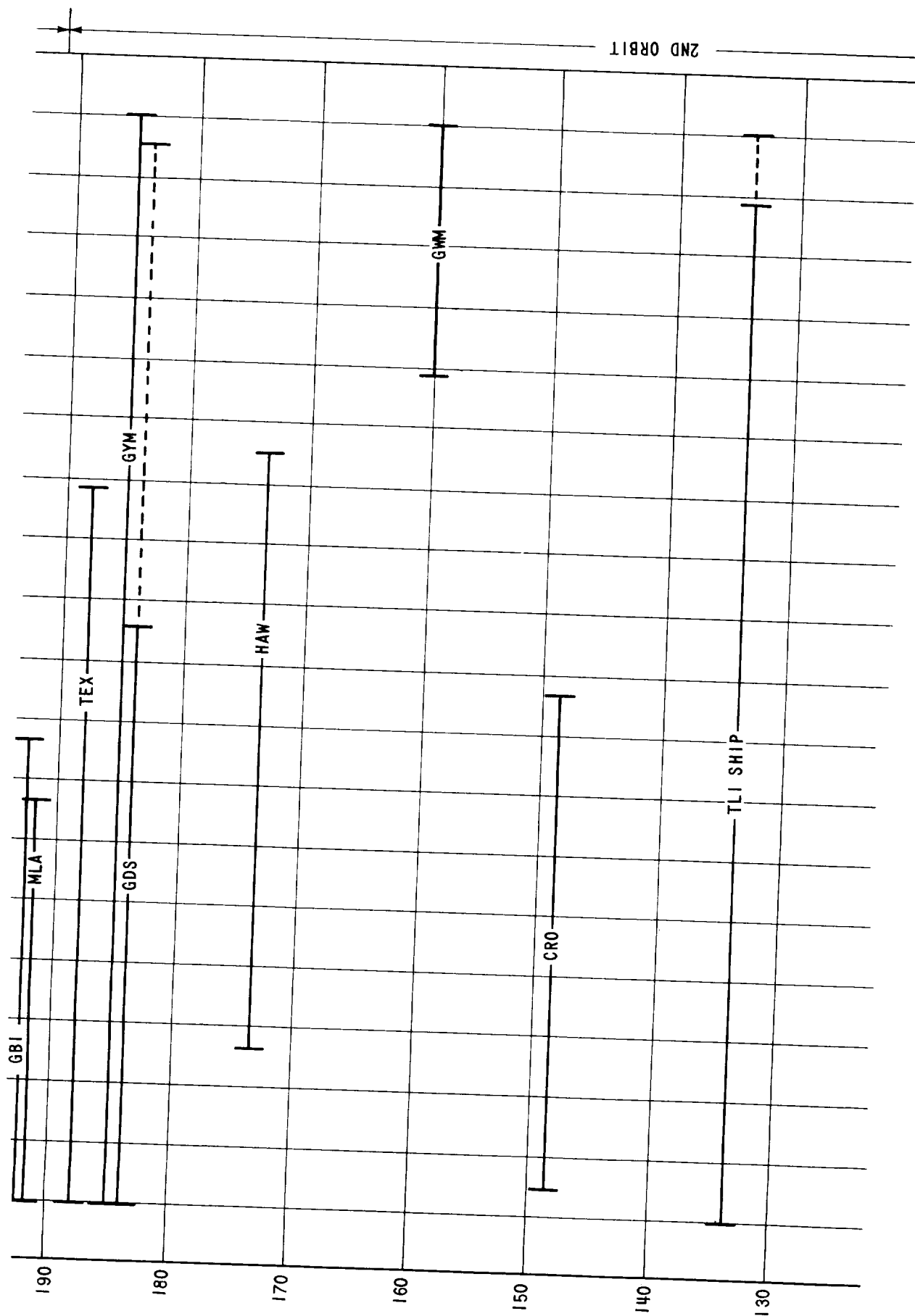
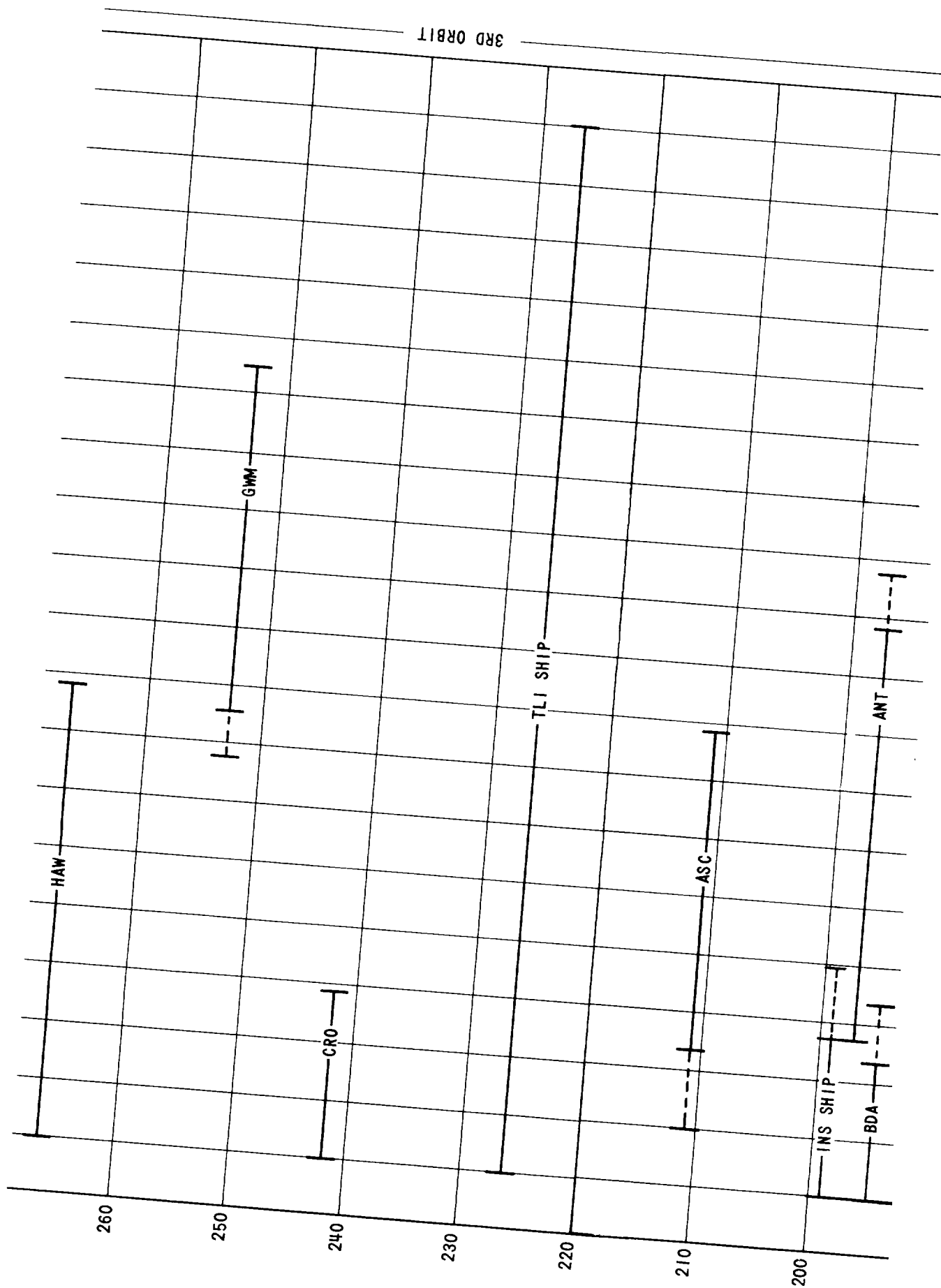


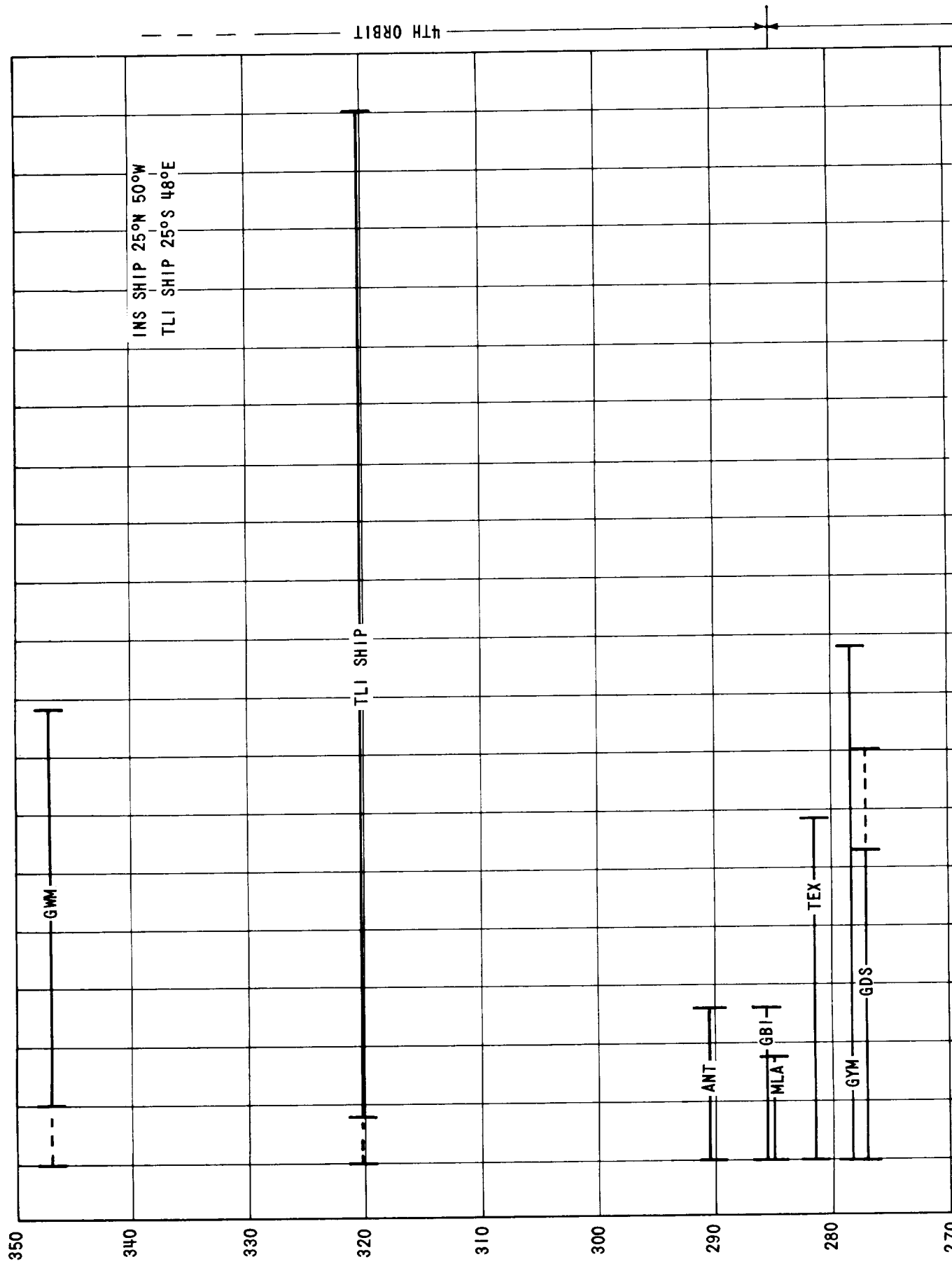
FIGURE 4b - S-BAND TRACKING COVERAGE DURING EARTH PARKING ORBIT
WITH 15° KEYHOLES (EXCEPT 6° KEYHOLES AT BERMUDA)

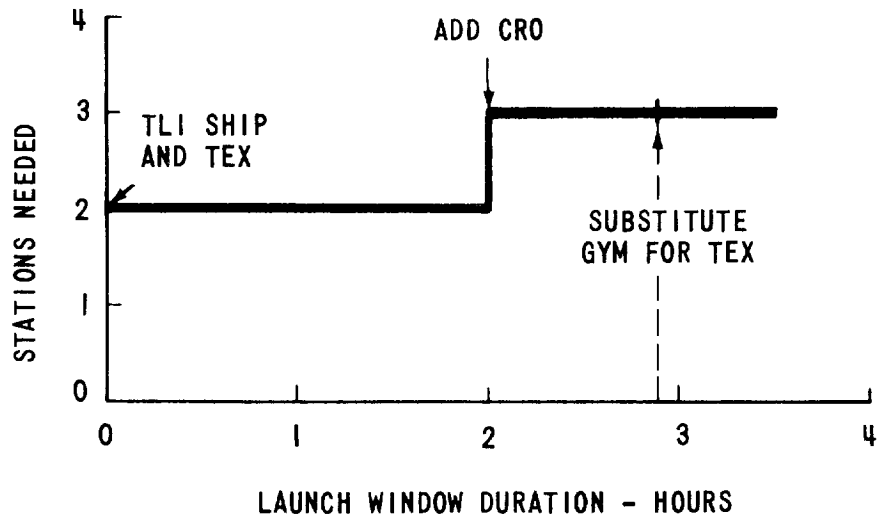


TIME SINCE LIFT

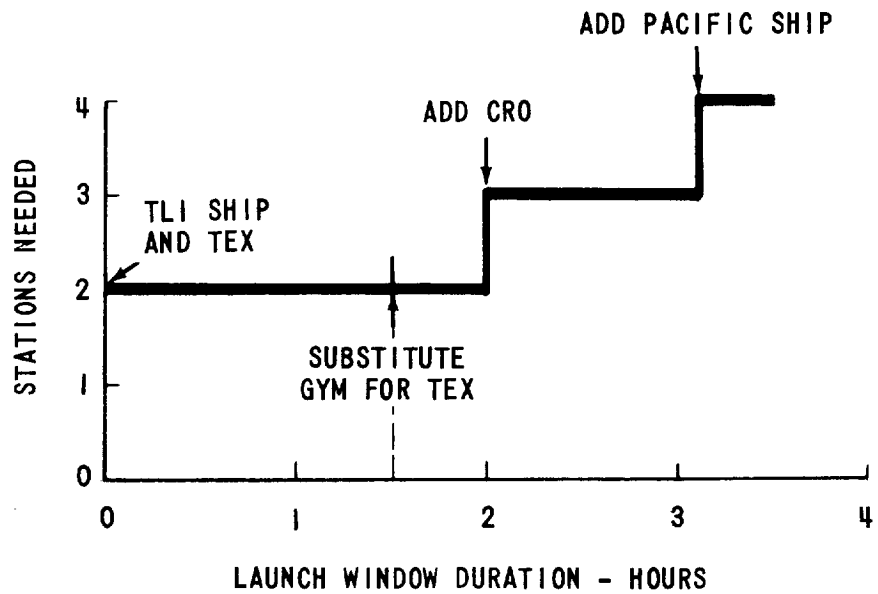








(a) 10° KEYHOLES



(b) 15° KEYHOLES

FIGURE 5 - NUMBER OF MSFN STATIONS NEEDED TO SATISFY PARKING ORBIT AND PRE-TLI REQUIREMENTS

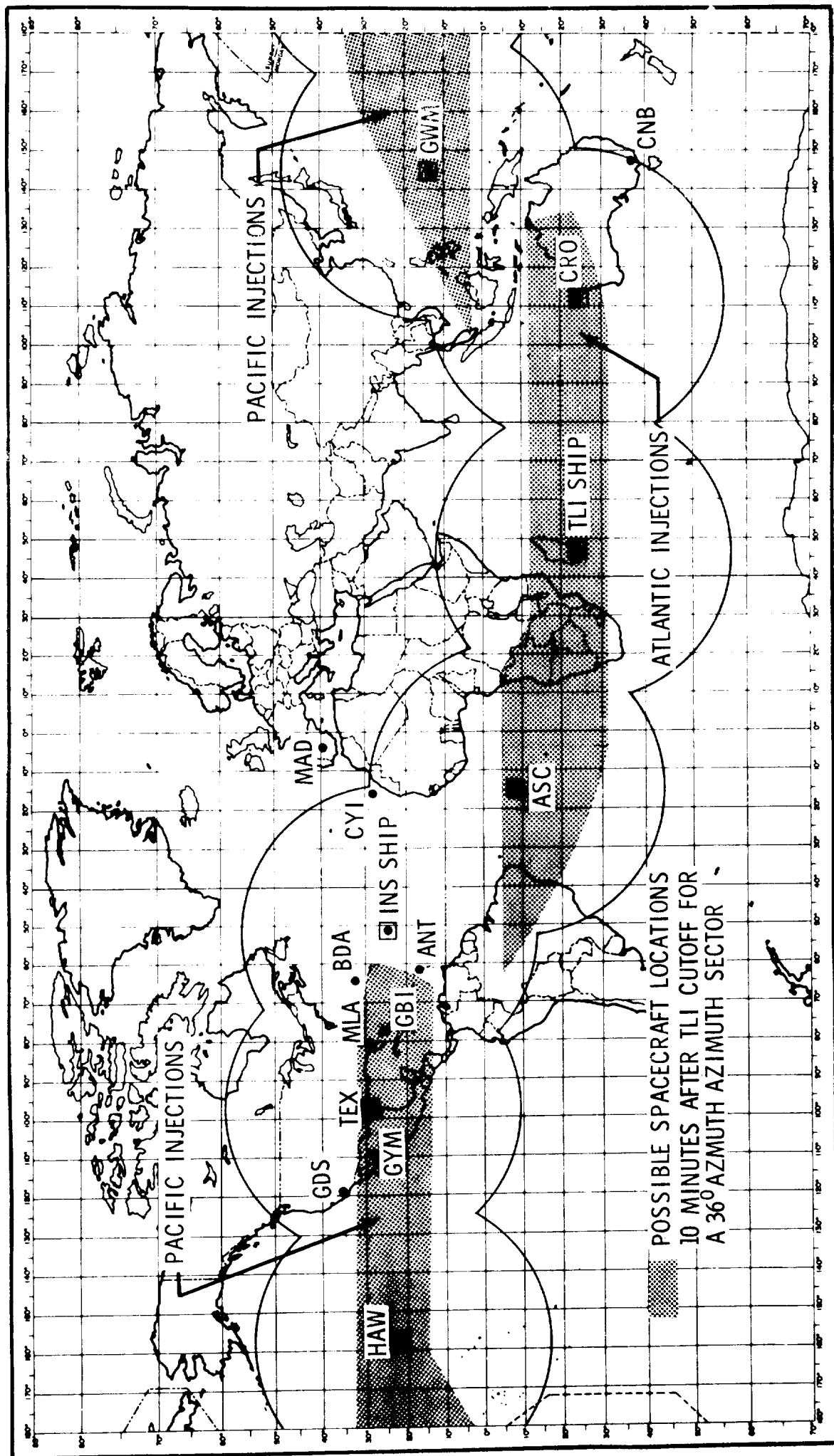


FIGURE 6 - S-BAND COVERAGE 10 MINUTES AFTER TLI CUTOFF (5° MASKING ANGLE)

LAUNCH	EPO & PRE-TLI	POST-TLI	LUNAR	SUM
MLA	X			X
GBI	X			X
BDA	X			X
INS SHIP	X	X		X
ANT				
CYI				
MAD			X	X
ASC		X		X
TLI SHIP	X (0 < L.W. < 3.5 HR.)	X		X
CRO	X (2.0 < L.W. < 3.5 HR.)	X		X
CNB			X	X
GWM		X		X
HAW		X		X
GDS			X	X
GYM	* (2.9 < L.W. < 3.5 HR.)	**		*
TEX	* (0 < L.W. < 2.9 HR.)	**		*
PAC SHIP				

•GYM MUST REPLACE TEX FOR WINDOWS > 2.9 HR.; GYM AND TEX ARE INTERCHANGEABLE FOR WINDOWS < 2.9 HR.

••GYM AND TEX ARE COMPLETELY INTERCHANGEABLE FOR POST-TLI COVERAGE

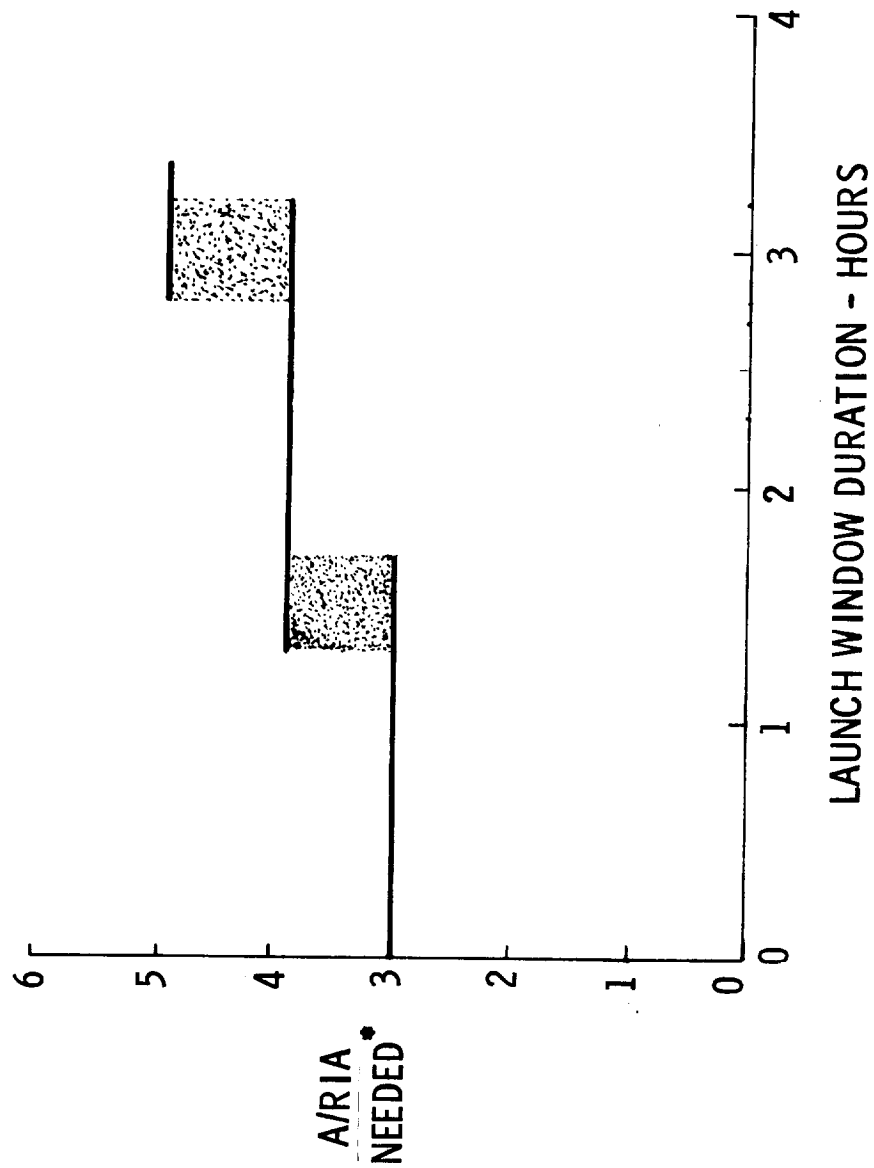
FIGURE 7a - TRACKING STATION REQUIREMENTS WITH 10° KEYHOLES

	LAUNCH	EPO & PRE-TLI	POST-TLI	LUNAR	SUM
MLA	X				X
GBI	X				X
BDA	X				X
INS SHIP	X		X		X
ANT					
CYI					
MAD				X	X
ASC			X		X
TLI SHIP		X (0 < L, W. < 3.5 HR.)	X		X
CRO		X (2.0 < L, W. < 3.5 HR.)	X		X
CNB				X	X
GWM			X		X
HAW			X		X
GDS				X	X
GYM		* (1.5 < L, W. < 3.5 HR.)	**		*
TEX		* (0 < L, W. < 1.5 HR.)	**		*
PAC SHIP		X (3.1 < L, W. < 3.5 HR.)			X (> 3.1 HR.)

*GYM MUST REPLACE TEX FOR LAUNCH WINDOWS > 1.5 HR.; GYM AND TEX ARE INTERCHANGEABLE FOR WINDOWS < 1.5 HR.

**GYM AND TEX ARE COMPLETELY INTERCHANGEABLE FOR POST-TLI COVERAGE

FIGURE 7b - TRACKING STATION REQUIREMENTS WITH 15° KEYHOLES



*NOT INCLUDING SPARES

FIGURE 8 - A/R/A NEEDED* AS A FUNCTION OF LAUNCH WINDOW DURATION

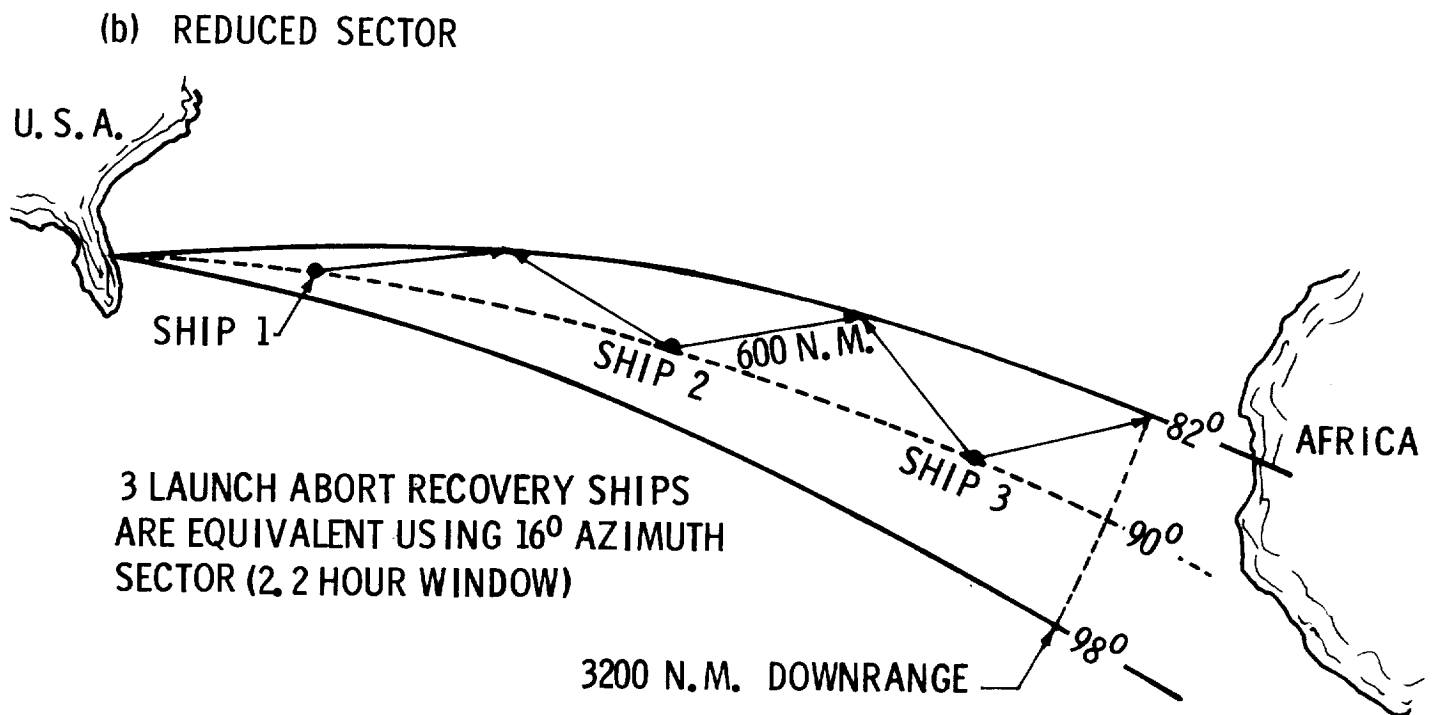
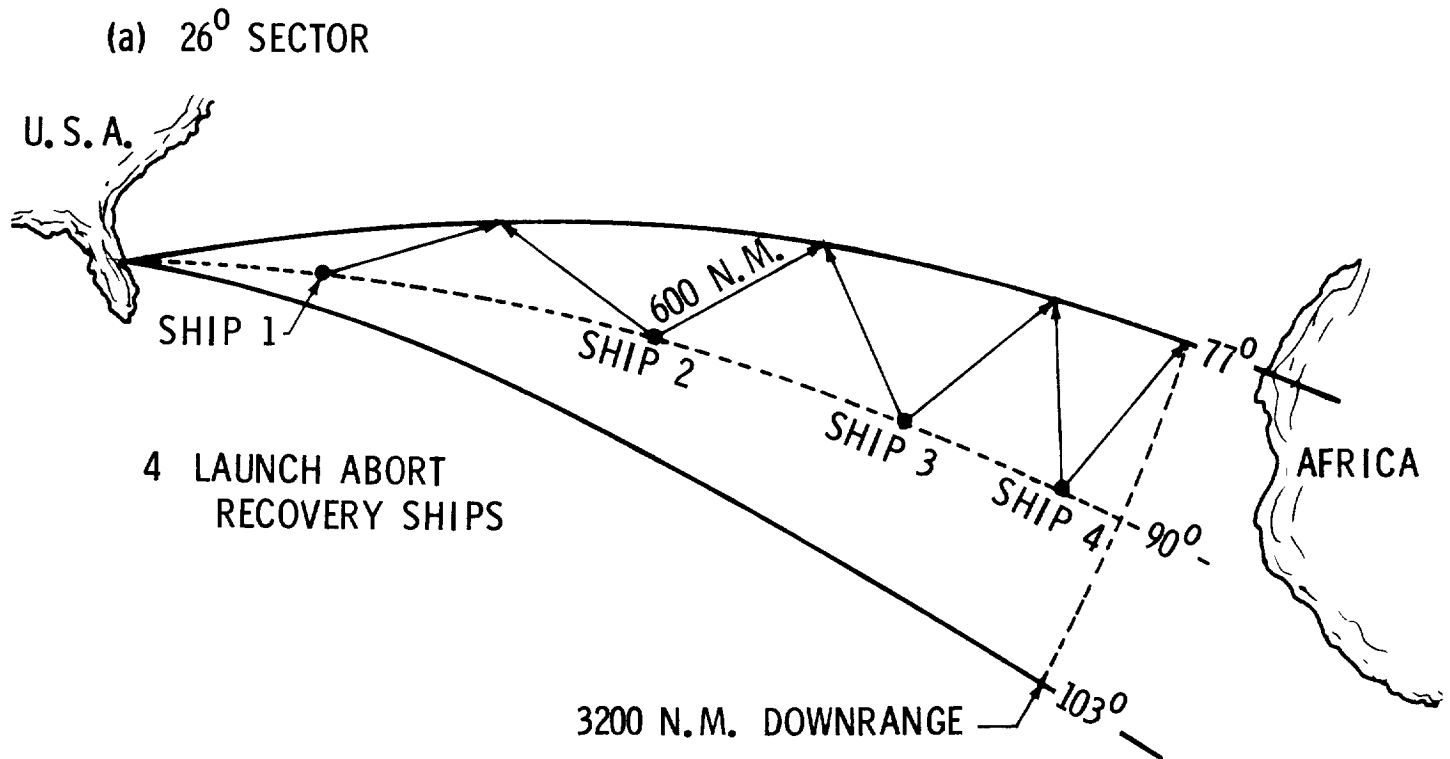
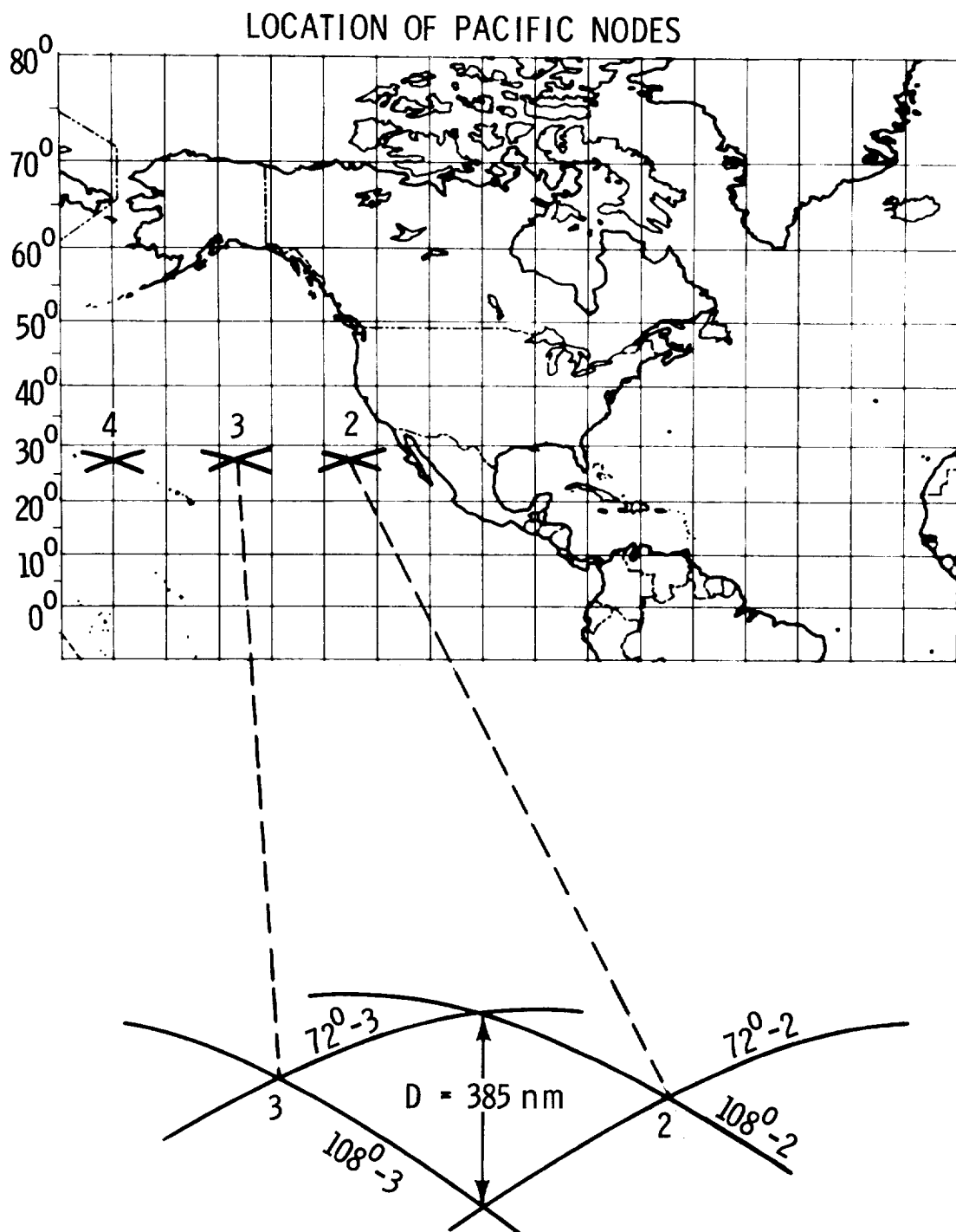


FIGURE 9 - LAUNCH ABORT RECOVERY GEOMETRY



BOUNDED AREA ILLUSTRATES FULL 36° AZIMUTH SECTOR

FIGURE 10 - PACIFIC ABORT RECOVERY GEOMETRY

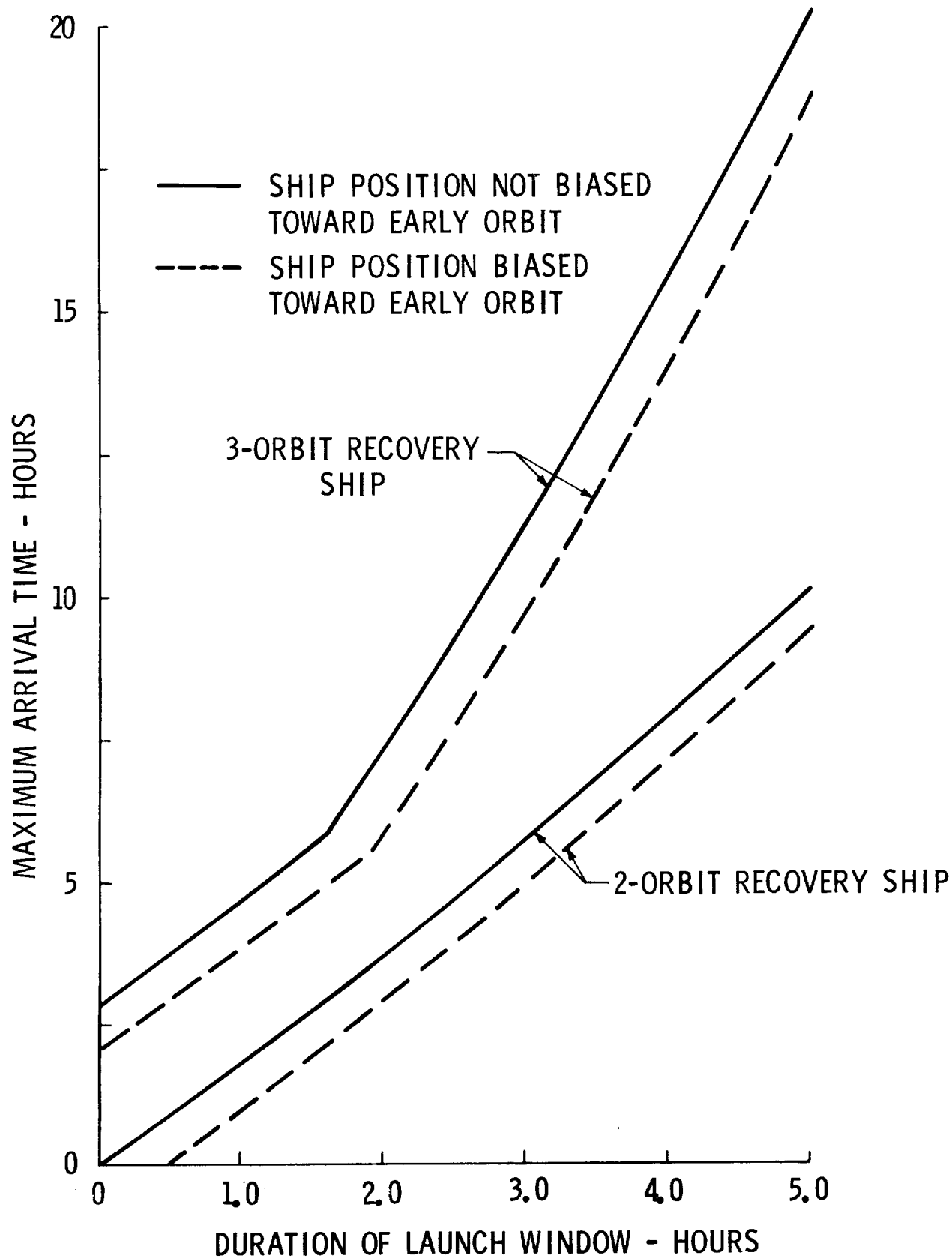


FIGURE 11 - MAXIMUM PACIFIC EARTH ORBIT ABORT ARRIVAL TIMES